MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

AUGUST 2002

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THE WIRELESS ARCADE
The next killer app for cell phones is games

CHEAP WIND POWER
Finally—a wind turbine to take on fossil fuels

WHY SOFTWARE IS SO BAD
(And how to fix it)

ANTIBODY DRUG REVIVAL
An old strategy provides new drugs for cancer and AIDS

GHANA'S DIGITAL DILEMMA
The digital divide is real—but not what you think

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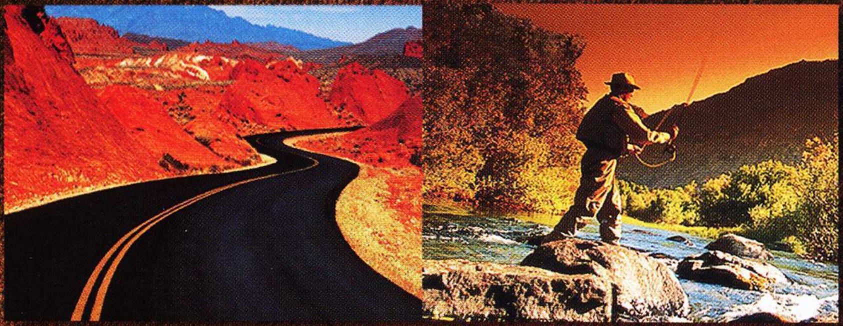

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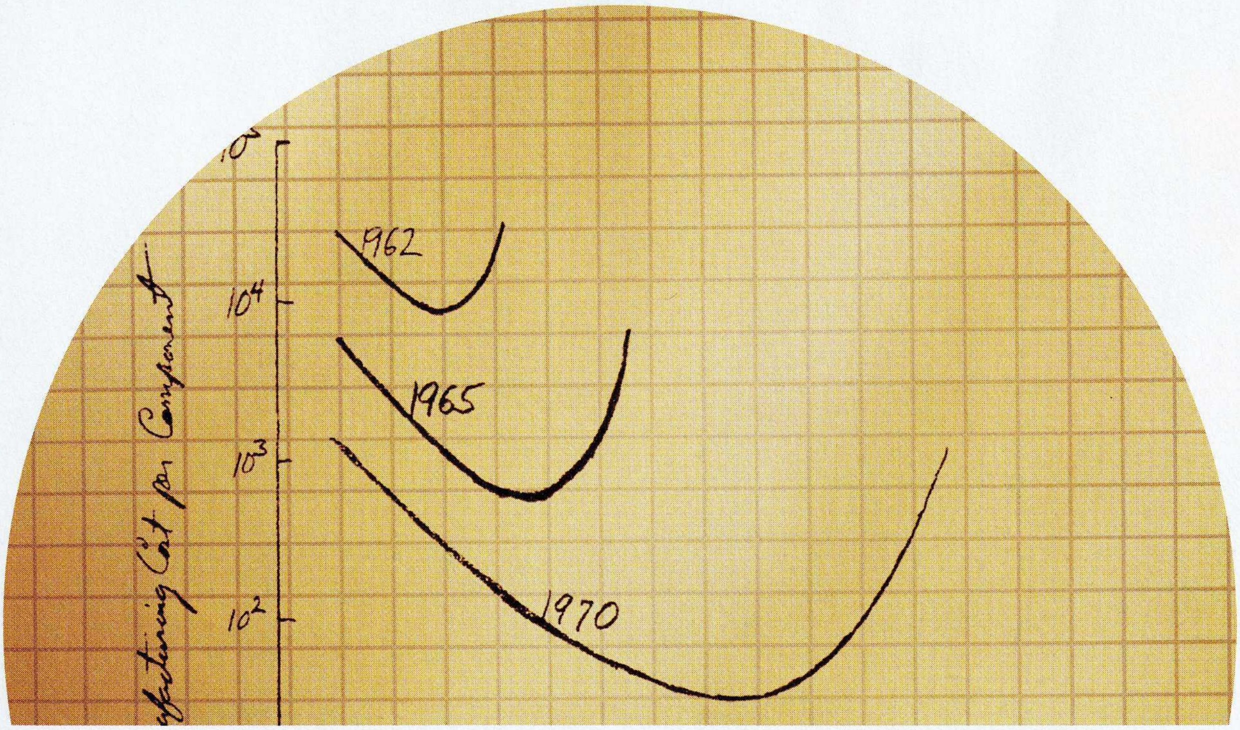

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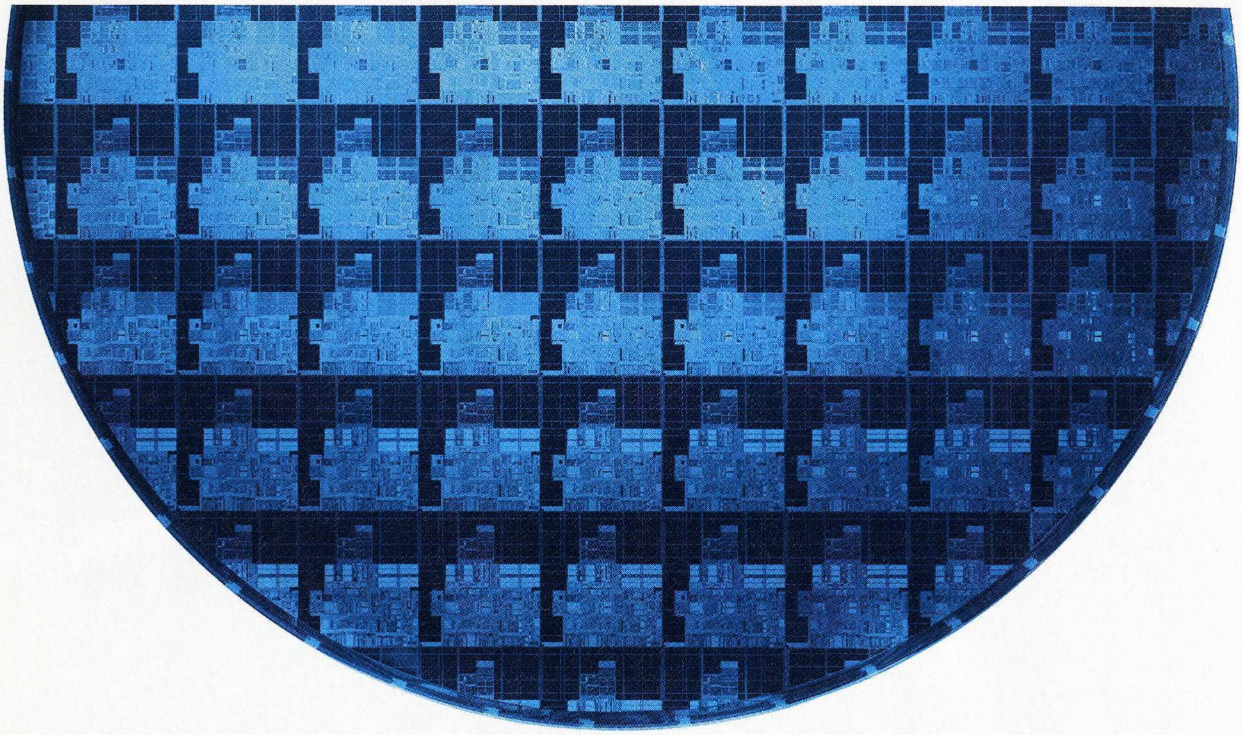

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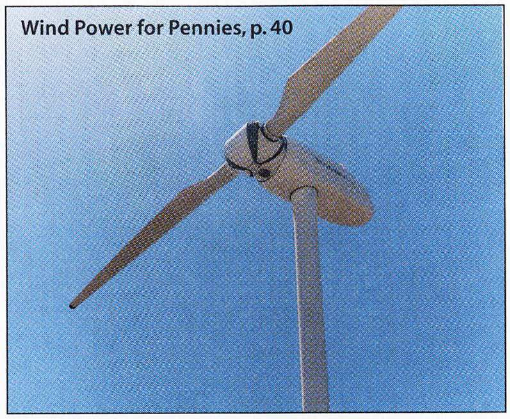

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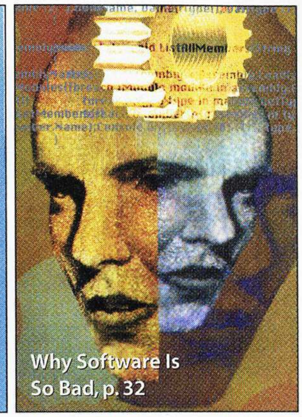

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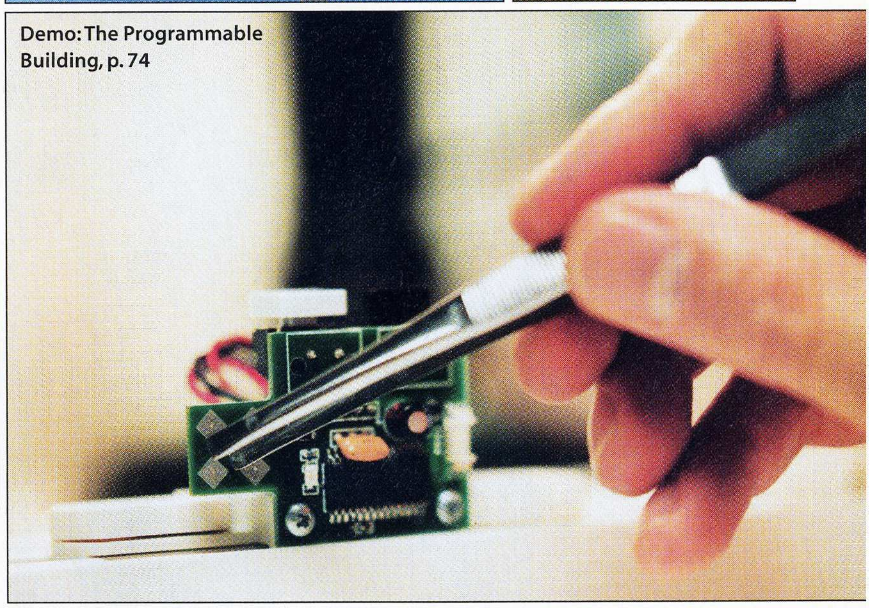

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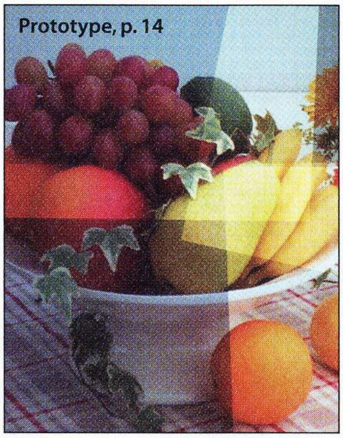
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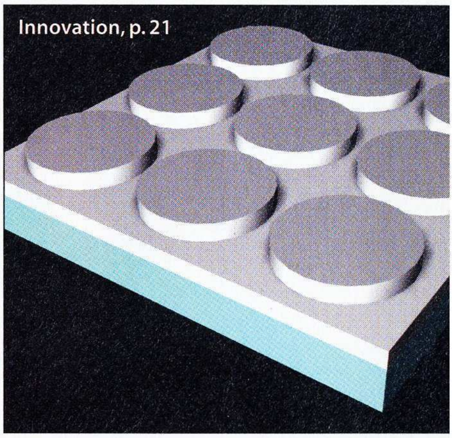
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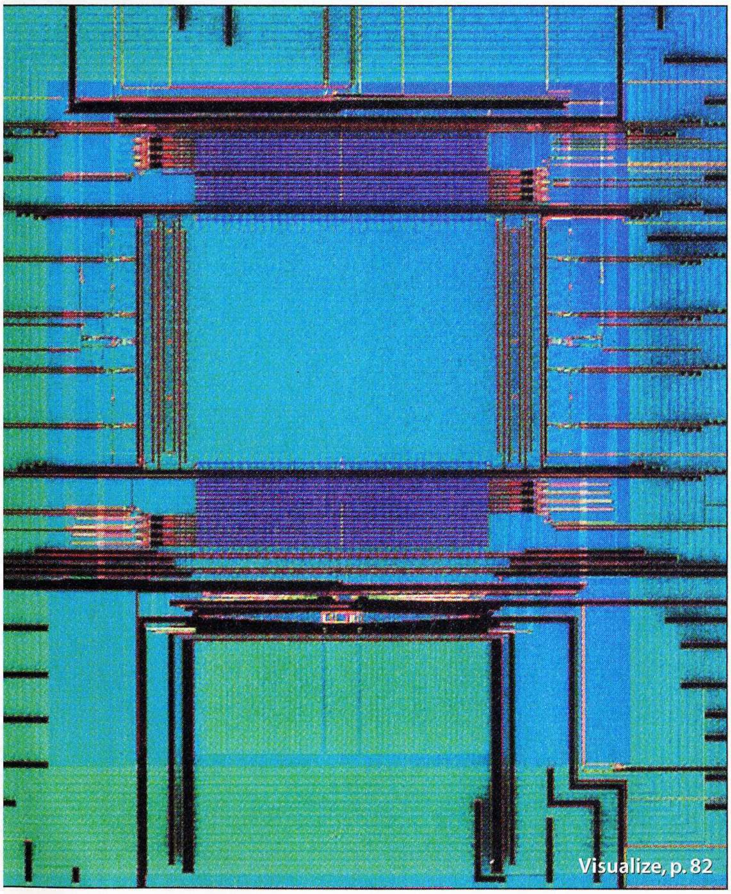
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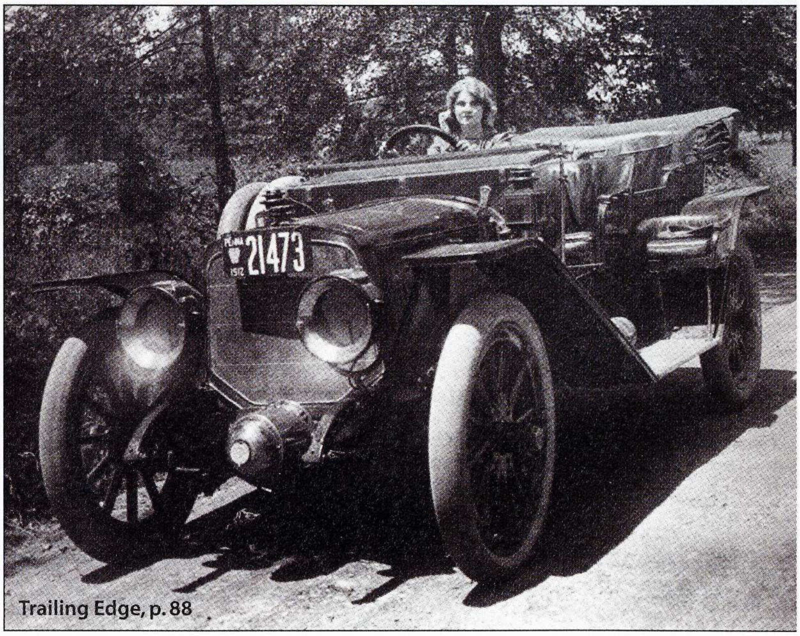

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LESSONS FROM INNOVATION

Innovation constantly offers us interesting new stories, but we make sense of them by just as constantly looking to old stories. Indeed, that's how we learn: by coming up with enduring patterns that can guide us as we move forward. This issue of *Technology Review* showcases two fascinating stories from the front lines of innovation and challenges us to find the right analogues from the past to match them up with.

The first case study comes from software, as described with delightful vehemence by Charles C. Mann in "Why Software Is So Bad," starting on page 32. That software is lousy is a given. We all know it is, because we all use it every day. But we only occasionally stop to think about it. When the screen freezes, we sometimes fly into rage or panic if we've lost important work; but by and large, we just accept mediocre software as part of daily life, like the traffic here in Boston. You don't waste time asking why it's there, you just fight your way through it to get to your destination.

One virtue of good writers is that they *do* take the time to stop and ask why. Mann has taken a hard look at how software gets made (a lot like sausage and legislation, actually) and at some of the common explanations for why it turns out the way it does. It's relatively new, as technologies go. It keeps changing, to meet new demands (think of the Web browser). It's harder to test than other engineering products—even if it works well in a thousand cases, it can still fail in a thousand more. And if those explanations don't do it for you, you can resort to that last refuge, blaming the customer, as Nathan Myhrvold does. Users, he tells Mann, lack "self-awareness."

None of these explanations is very satisfying. Nor is it clear how to break software's vicious circle of bloat and revision. Mann concludes that litigation—lots of it—will be needed before software makers decide simplicity and reliability are pretty good ideas after all. Nobody likes litigation, but Mann concludes that lawsuits over software product liability are a "bad idea whose time has come."

What's interesting about this story is the underlying question of what it takes for a particular technology to achieve a level of reliability high enough that it fades into the background of our lives. When, for instance, did flying become so safe that fear of flying became a subject for "therapy"? For that matter, when did the railroads' atrocious early safety record improve sufficiently that a train trip was a clean, safe, predictable experience? Do these transformations flow naturally from the piling up of technological improvements? Or is a combination of improved technology, economics and government intervention required? In answering those questions, we'll get closer to understanding what it takes to make software better.

The second case study from this issue isn't so much about policy; it's more like an observation about how innovation happens, how a technology "designed" for one purpose gets colonized by another, quite different one. In this case the technology is the cell phone, which, according to writer David Kushner, is about to be taken over by video games. All of us, Kushner says, young and old, male or female, may soon spend our previously "wasted" moments—in doctors' waiting rooms, airports, ticket lines, etc.—using cell phones to play video games, sometimes competing with folks in, say, Japan, where this craze has already achieved liftoff velocity.

This prediction, for which Kushner makes a persuasive case, reminds me of the early history of the cell phone's predecessor, the telephone. The first telephones were rare and precious commodities, treated with the respect rarity commands. For the most part they were in government or business offices, in special cabinets, taken out with ceremony, to be used for transmitting grave information in real time.

As I take my leave of *Technology Review*, I'd like to offer two lessons that represent a lot of what we've learned in the last four years. And I wish the *TR* community all the best in the future.

Fast-forward only a couple of decades and think of the archetypal 1950s teenager talking on her pink Princess phone. The telephone had become ubiquitous, demotic, and used for purposes of low specific gravity. Similarly, the cell phone, not long ago a high-priced status symbol for self-important business types, may in short order become primarily an arcade for crude, colorful video games.

These two lessons—that technological transformation often is not simply a matter of cumulative improvements and that innovations frequently find their widest applications in unforeseen arenas—represent a lot of what we've learned about innovation at *Technology Review* in the last four years, since we relaunched the magazine as MIT's Magazine of Innovation.

And those two lessons are as good a place as any to take my leave of you. This issue is my last as editor in chief of *Technology Review*. Editing this magazine has been a wonderful experience. I'm proud of the solid foundation we've laid down in the last four years, and I have no doubt that our superb editorial team will continue to deliver the quality you expect. As for me, I'm moving on to exciting new challenges, and I'm sure you will hear from me again in the realm of science and technology. It has been a privilege to be part of the *Technology Review* community. And I'd love to hear from you again with your thoughts and insights. Let's keep in touch. E-mail sent to John.Benditt@TechnologyReview.com will reach me. —*John Benditt*

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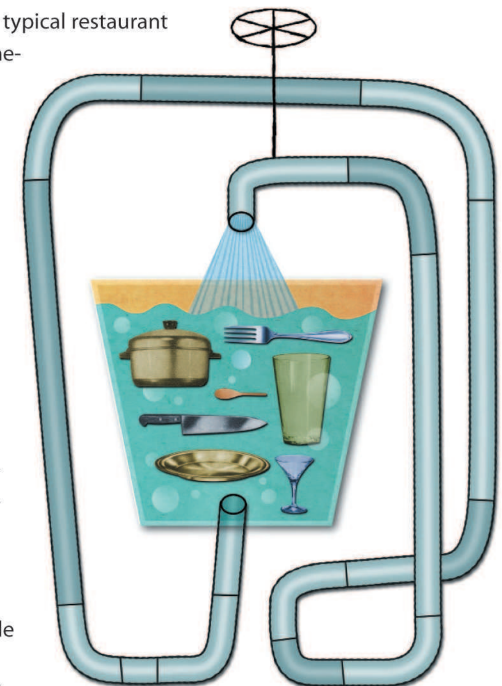
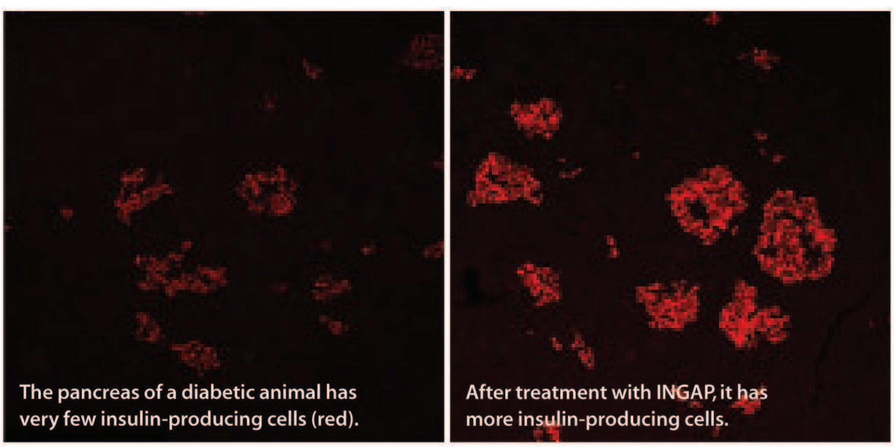
STRAIGHT FROM THE LAB: TECHNOLOGY'S FIRST DRAFT

GREASY-SPOON CLEANER

The frenzied cooking and cleaning in a typical restaurant generates large volumes of water permeated with oil and grease. While big restaurants can afford their own wastewater treatment facilities, smaller establishments usually discharge wastewater straight into the closest sewer systems. Chemical engineers at the Hong Kong University of Science and Technology have developed a compact and inexpensive technology for cleaning restaurant wastewater.



The device consists of a set of catalysts and aluminum electrodes fitted inside a small tank. When the electrodes are powered up, the fine oil droplets in the wastewater fed to the tank shed their negative charges and begin to clump together. One electrode generates tiny hydrogen bubbles that carry the coagulated grime to the surface, where it can be skimmed off. Water purified by the process can be used for cleaning and other non-drinking purposes, according to project leader P. L. Yue. A Hong Kong-based company collaborating with Yue's group expects to bring the technology to market in about two years.



The pancreas of a diabetic animal has very few insulin-producing cells (red).

After treatment with INGAP, it has more insulin-producing cells.

DESTROYING DIABETES?

Diabetics could one day live lives free of needles and implants thanks to a new treatment that can prompt the body to generate new insulin-producing cells. Researchers Aaron Vinik of Eastern Virginia Medical School and Lawrence Rosenberg of McGill University discovered that a fragment of a protein known as INGAP stimulates cells in the pancreas of adult animals to develop into "islet" cells that make insulin in response to blood sugar. In animal experiments, a few weeks of daily injections of the protein segment yielded normal blood sugar and insulin levels. GMP of Fort Lauderdale, FL, which licensed the technology, has started human trials in patients with both Type 1 (juvenile) and Type 2 (adult onset) diabetes. The treatment could become available in about five years. One question that remains is whether Type 1 diabetics, whose bodies have destroyed their own islet cells, would be able to sustain the new cells without immune suppression.

MEGA MEMORY

Computer hard drives store massive amounts of information, but they write and retrieve it slowly. University of Houston physicist Alex Ignatiev has developed a new memory chip that could perform such tasks in an instant. In the short term, the chips might replace the slow and expensive flash memory cards used in digital cameras and deliver "nonvolatile" random access memory that will retain data even if a PC crashes.

To store data, the chip changes the electrical resistance of a thin film of metal oxide by sending a small electric current through it. Besides being faster, Ignatiev says, the new memory should be cheaper and more energy efficient than flash memory and various other stable-memory technologies under development. Electronics maker Sharp has exclusively licensed the technology and expects to begin marketing the chips in three to five years.

DRIVE THE WAVE

Turbochargers give hot rods screeching-fast acceleration, using the force of exhaust gases to spin a turbine and compress air flowing into combustion chambers. But there's a slight lag after you hit the gas, and it gets worse as the engine gets smaller, making the technology impractical for economy cars. Work at the Swiss Federal Institute of Technology in Zürich has yielded a turbocharger variant without this problem. The "pressure wave supercharger" eliminates mechanical steps; the exhaust directly compresses clean intake air in rotating chambers. Early versions proved difficult to control, with exhaust tending to mix with the intake air. To prevent this, mechanical engineer Lino Guzzella's team uses sensors and actuators that continually alter rotation speed and adjust airflow. Guzzella says the device could enable a peppy car that gets 28 kilometers per liter in city driving, and could reach market within three years.

Exhaust compresses clean air inside cylinder.

COURTESY OF SWISS FEDERAL INSTITUTE OF TECHNOLOGY (WAVE); COURTESY OF STRELITZ DIABETES INSTITUTES AT EASTERN VIRGINIA MEDICAL SCHOOL (DIABETES); JOYCE HESSELBERTH (ILLUSTRATION)

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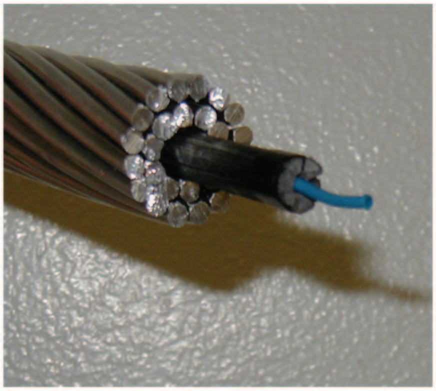


POWER BOOST

Americans are notorious electricity hogs, but a new power line design could help satisfy their appetite. Many power lines—usually steel-reinforced aluminum cable—are 30 to 70 years old and were never meant to handle the loads they're carrying. Torrance, CA, engineering firm W. Brandt Goldsworthy has developed a stronger, lighter alternative that carries 40 to 200 percent more electricity—and can transmit high-speed digital data to boot. The new cable consists of a reinforced plastic core with a hollow space at the center for optical fiber; the core is wrapped with aluminum alloy wires. Unlike steel, the nonconducting plastic draws no electricity from the aluminum conductor; this prevents the novel cable from heating up and sagging and allows it to carry more juice. The optical fiber could help carriers bring broadband Internet connections into neighborhoods without digging up roads to lay new cables. The California Energy Commission will field test the cables this summer, most likely in Southern California Edison's grid.

CELL SENSOR

Most sensors used to measure pollutants in lakes and rivers fail to detect small concentrations that may still be harmful to humans. Researchers at the University of Tokyo's Institute for Industrial Science have designed an ultrasensitive device that uses human cells to detect these low but hazardous levels.

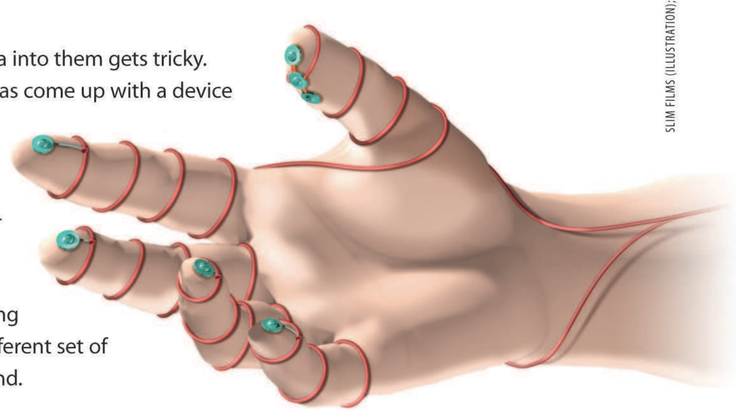
The sensor consists of a fine plastic tube containing lab-grown human cells. A sample of water is poured into the tube, along with a low-density lipoprotein (a compound made of fat and protein) tagged with a fluorescent dye. Toxic chemicals in the water slow down cells' uptake of the lipoprotein, resulting in dimmer fluorescence. In preliminary tests, the disposable sensor detects the presence of small traces of such poisonous compounds as lead nitrate, acetaldehyde and sodium arsenite (all of which impede lipoprotein uptake) in two hours, versus the two days that conventional laboratory sensors would need to register them. Yasuyuki Sakai, one of the scientists who developed the device, says it could take up to five years to bring it to market.

PROJECTION PERFECTION

A few digital projectors can make a big impression, beaming presentations or advertisements onto entire walls. But making their images seamless requires costly and time-consuming calibration of fixed projectors. Researchers at Mitsubishi Electric Research Laboratories in Cambridge, MA, have devised a way to do the same job in 10 seconds with software and a cheap camera—say, a Web camera—enabling portable, lower-cost systems. First, several projectors are placed in roughly the right places, each beaming a checkerboard pattern onto the wall. The camera registers the relative alignment of these displayed grids. Finally, software alters each projector's image fragment—twisting, rotating or bending it as needed *(above)*—so that the full image appears seamless. Such units could be used in stores, offices or even homes, where "any wall can become a projection TV," says system designer Ramesh Raskar, a computer scientist at Mitsubishi, who adds that the system should reach market within two years.

THUMB TYPING

As computers blend into our environment and even our clothing, entering data into them gets tricky. Carsten Mehring, a mechanical engineer at the University of California, Irvine, has come up with a device that turns your hands into a qwerty-style keyboard. Mehring's device uses six conductive contacts on each thumb—three on the front and three on the back—to represent a keyboard's three lettered rows. Contacts on the tips of the remaining eight fingers represent its columns. Touching the right index finger to the middle contact on the front of the right thumb, for instance, generates a *j*. The top contact on the thumb yields a *u*, while the middle contact on the back of the thumb would produce an *h*. Mehring says the similarity to typing makes his input device easier to master than others that require an entirely different set of motions. He has applied for a patent and hopes to market a product by year-end.



SLIM FILMS (ILLUSTRATION); MITSUBISHI ELECTRIC RESEARCH LABS (PROJECTION); COURTESY OF GOLDSWORTHY AND ASSOCIATES (POWER BOOST)

GARBAGE IN, INNOVATION OUT

History proclaims that James Watt's reinvention of the (Thomas) Newcomen steam engine with Matthew Boulton launched the Industrial Revolution and transformed the world. But history politely downplays the key business reason why people actually bought those early Boulton and Watt betas.

The answer isn't pretty; in fact, it's dank, it's wet, and it stinks. Britain's coal mine operators bought these newfangled and much improved steam engines for the same reason they had purchased the original Newcomen engines—to pump out filthy water that seeped into their mine shafts and interfered with operations. More powerful pumps meant deeper, drier and thus more profitable mines. For all intents and purposes, the Boulton and Watt steam engine initially made its money as a waste disposal unit. Going down the waste pumping learning curve generated the innovations that turned steam engines into the world's most pervasive and profitable source of industrial power.

There's a deeper lesson here. In practical terms, "waste management" and "innovation management" still have more in common than not. Failing to appreciate the economics of waste is a waste of economics. Waste—in all its myriad forms—is a resource that constantly redefines innovation opportunities.

Let's go back to the coal mines. Just as wastewater created the market in steam engine innovation, the waste product of coal mining and refining—coal tar—enabled a revolution in chemistry. The growing abundance of coal tar led directly to the rise of the synthetic-dye, photographic-film and pharmaceutical industries. Aniline, film and aspirin were all lucrative (by-)products of coal tar. Waste provided an embarrassment of riches. Indeed, within a generation, these "waste" products became more valuable businesses than mere coal.

Opportunistic waste management is a transcendental theme in industrial innovation. As economies-of-scale-driven assembly lines came to dominate the industrial landscape, notions of waste became better defined and refined. Meatpackers, for example, soon made lots of money from the oleomargarine, glue and knife handles—made out of shinbones—that had previously been treated as organic scrap. In Cincinnati—a.k.a. Porkopolis—Gustavus Swift bragged that his slaughterhouses had become so sophisticated that they used "everything but the squeal." The relentless pursuit of process efficiencies yielded serendipitous product innovations.

Henry Ford's innovation in treating "time" as a form of waste extended well beyond the production of automobiles. By experimenting with speedups and production techniques explicitly designed to slash manufacturing times, Ford radically altered the relationship between invention and innovation. You've probably heard the Ford adage that a customer could have any color Model T he wanted so long as it was black. But have you ever wondered why the only choice was black? Because black was the fastest-drying paint. Accelerating the pace of drying paint therefore became an essential part of mass automobile production.

So a twist on Ford's famous epigram "If it doesn't add value, it's waste" seems equally valid: "If it's waste, it can add value." The trick is to figure out a context where waste becomes an exploitable asset.

This sensibility is as important for postindustrial digital innovation as it is for material innovation. Where's the "waste" in the Internet? One obvious answer is processing power. Literally millions of microprocessors are underutilized relative to their capacity. There are gigaflops, teraflops and petaflops of processing power just begging to be exploited.

In fact, a few parallel-processing pioneers have begun to take advantage of this opportunity by turning the Internet into a giant global supercomputer. The SETI@home initiative, for example, invites people interested in the search for life on other worlds to "lend" their networked computers to the processing of cosmic radio signals during their idle times. Almost four million users worldwide have signed on.

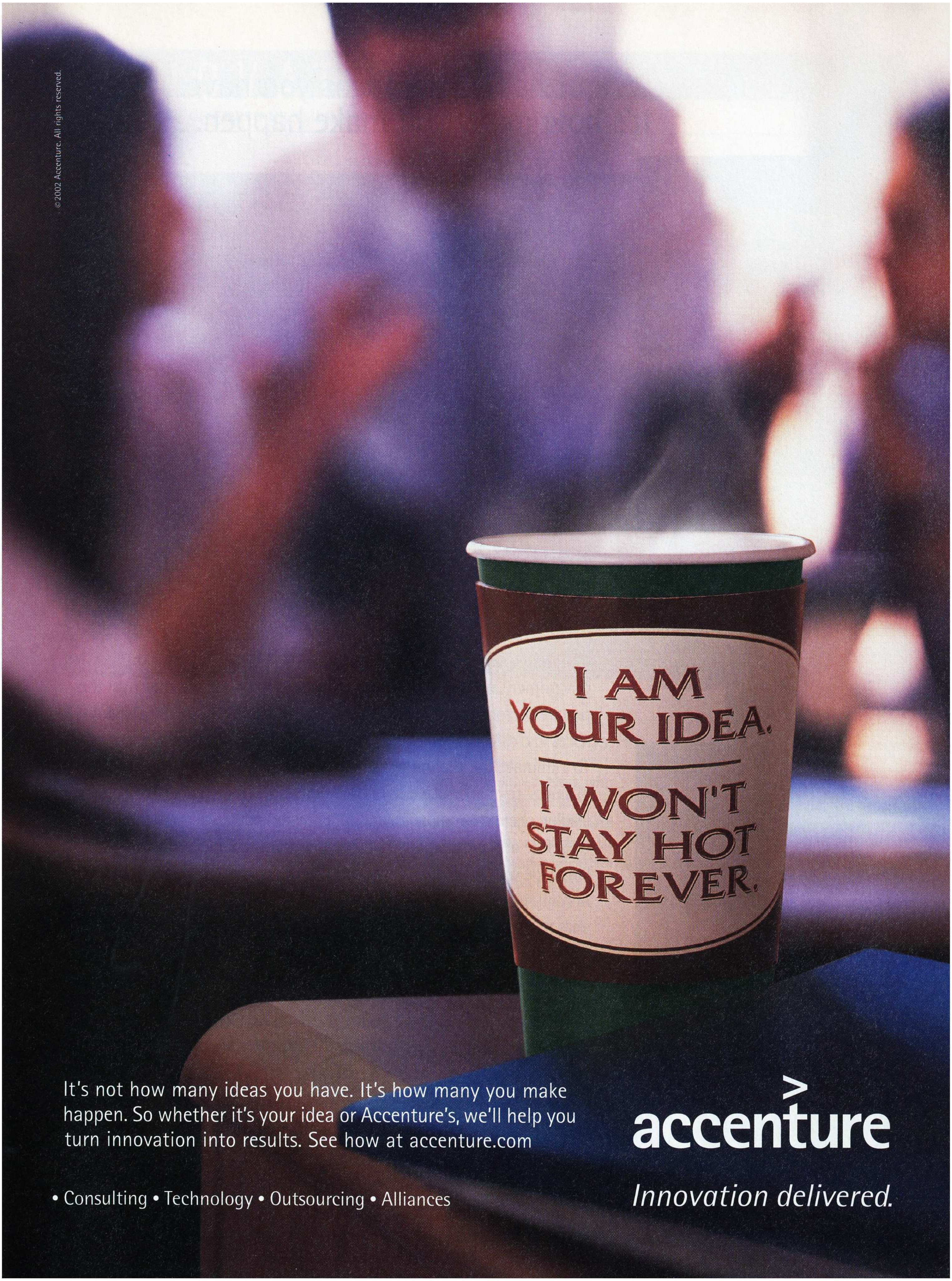
A twist on Henry Ford's famous epigram "If it doesn't add value, it's waste" seems valid: "If it's waste, it can add value." The trick is to figure out a context where waste becomes an exploitable asset.

Over the past year, molecular biologists at Oxford University's Centre for Computational Drug Discovery have created a comparable "screen-saver-driven" parallel-processing effort to turn idle processors into drug designers (www.chem.ox.ac.uk/curecancer.html). The goal is to test disease-causing proteins against a library of small molecules—potential drugs—to see if they might bind. (Binding is a prerequisite for a molecule to act as a drug.) Each user receives roughly 100 virtual molecules along with one target protein. The "hits" are transmitted back to Oxford for further analysis.

This is just the first wave of "waste-based" innovation in the Internet infrastructure. The next wave will spring from the answers to questions such as, How might processors and servers be used for self-diagnostics and repair? How might organizations create intranet-based supercomputers to better manage their information and themselves?

As for the future of postindustrial "waste management": as surely as the chemical and pharmaceutical industries rose from the detritus of coal mining, history suggests that new industries will arise from the detritus of semiconductors, software and switching.

Anticipating the next generation of waste-driven innovation may be difficult, but it surely won't be a waste of time. TR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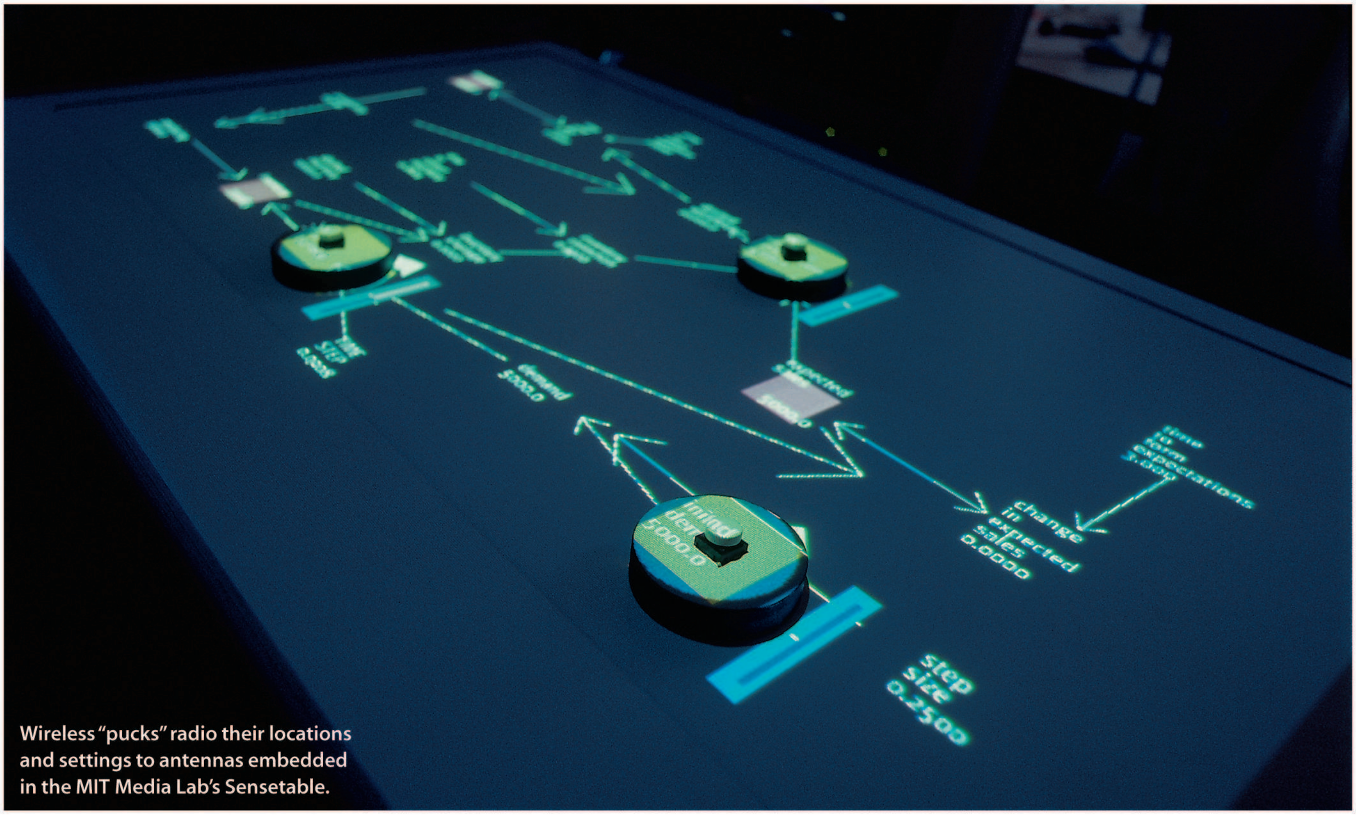


Wireless "pucks" radio their locations and settings to antennas embedded in the MIT Media Lab's Sensetable.

DANIEL VANACKERE

TAKING HOLD OF SUPPLY CHAINS

A "tangible interface" turns simulations into collaborations

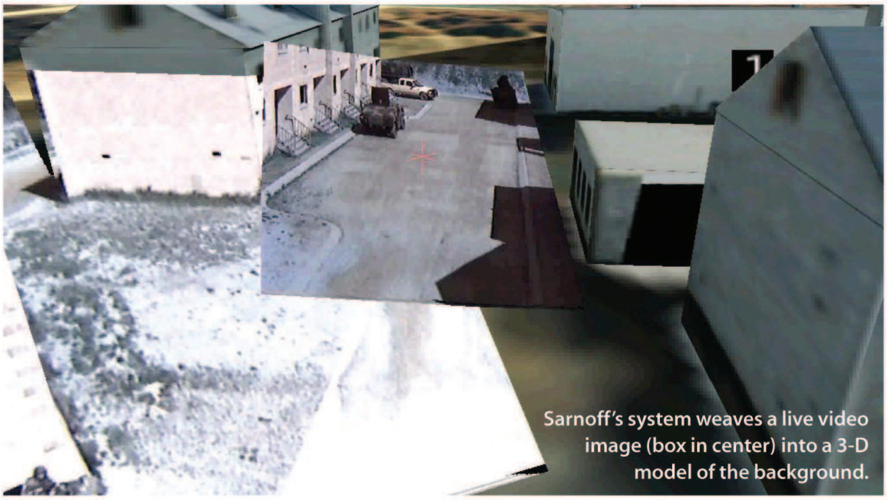
Neville at the warehouse calls Sophie at the factory to tell her that surging demand has almost depleted the company's stock of microchips. Alarmed, Sophie orders piles of raw materials to build more chips. Three months later the warehouse is restocked, but now Neville says demand has fallen off. Sophie immediately stops ordering materials—only to see demand rebound, resulting in a new chip shortage.

Unintentional feedback loops like this are rife in business, and they're hard for managers to tame without knowing which loops cause the most damage and therefore should be tackled first. They're also costly; word of supply chain glitches typically degrades a firm's stock price by 20 percent, according to researchers at the Georgia Institute of Technology. While computer simulations of supply chain fluctuations help, they're hard to interpret or operate collaboratively. Now, with the aid of a tabletop computer interface invented at the MIT Media Laboratory and funding from Intel, researchers at MIT's Sloan School of Management are giving managers a hands-on feeling—literally—for the factors that can mend or upend their supply chains.

The system is one of a number of "tangible interfaces" being developed at places like MIT, Mitsubishi and the Oregon Graduate Institute to do everything from simulating business processes to augmenting communication in military command centers. Sloan professor Thomas Malone says the MIT system is designed to "get everyone playing together," exploring "what-if" scenarios such as the effects of building more warehouses or changing shipping routes.

A supply chain simulation starts with graphics projected from overhead onto a Media Lab creation called the Sensetable. Users can place wireless "pucks" on specific areas of the surface—for example, a graph of inventory versus time—then turn a dial atop the puck to strengthen or weaken the parameters affecting the graph, with repercussions immediately displayed on related tables and graphs. A group of managers studying Sophie and Neville's problem, for example, might try varying the time delay between inventory reports and raw-materials purchases, perhaps finding that inventories stabilize when Sophie waits a week before acting on Neville's information.

"Supply chains are these things that everybody talks about, but nobody can see," says Intel director of information technology-industry business research Mary Murphy-Hoye, who initiated Intel's investment in the project. "Introducing a degree of tangibility could change the nature of the conversation."
—*Wade Roush*



Sarnoff's system weaves a live video image (box in center) into a 3-D model of the background.

REAL-WORLD VIDEO GAME

SECURITY | The producers of the 1999 sci-fi martial-arts extravaganza *The Matrix* used elaborate and costly movie camera technology to circle around characters frozen mid-kung-fu kick. Such vertiginous visual effects can now be generated on the cheap from live images provided by stationary video cameras. But even more pertinent in the post-September 11 era, the package of video-processing and 3-D modeling technologies delivering these tricks promises to set a new standard for surveillance and security systems—and bring new meaning to the term "reality programming."

The system, developed at Sarnoff in Princeton, NJ, allows users to joystick their way through a live, 3-D scene as if it were the latest video game. Indeed, by stitching together scenes captured by dozens or hundreds of networked cameras, the technology makes it possible to conduct a virtual patrol of an entire urban center, or every hallway in a building, in real time. "It's difficult for eyeballs to make sense of what a collection of cameras sees. This is an integrated way to use hundreds of cameras to make one display," says Rakesh Kumar, computer scientist and lead developer of the technology, dubbed "Video Flashlight."

What makes the new system so unusual is that it melds 3-D models of a background scene—say, a cluster of buildings—with real-time camera views of the same area. Image-processing chips developed at Sarnoff detect new or moving objects, construct 3-D images of these objects, and integrate them into the model. New software for "tweening"—filling in the gaps between video frames—lets security personnel "fly" around a subject such as a pedestrian, getting a detailed look without jumping between widely separated views. "This is beyond anything else out there" in vision processing, says Mari Maeda, a physicist who shepherded Sarnoff's project as a program manager at the U.S. Defense Advanced Research Projects Agency.

Uses of the technology could include marking and tracking individuals as they move, or setting off an alarm when an unusual pattern is detected, such as a large group of people entering a building. Sarnoff engineers say the system needs refinement—for example, they aim to make it work with cameras that zoom, pan and tilt, not just fixed ones. But early versions have already been installed at U.S. Army Intelligence headquarters and are under consideration for New York City's three airports—perhaps bringing us all a step closer to living inside the Matrix. —*David Talbot*

INFINITE DRUG DIVERSITY

CHEMISTRY | The genomics revolution has provided innumerable potential targets for new drugs. But many of these disease-causing proteins seem to be "undruggable": companies can't find compounds that inhibit them. Into this breach comes Boston startup Infinity Pharmaceuticals, which plans to use new chemical-synthesis methods to build more varied and complex drug candidates than have previously been possible.

Infinity's technique, pioneered by Harvard University chemist and company cofounder Stuart Schreiber, involves binding simple starting compounds to hosts of small plastic supports. The compounds acquire new chemical groups as they are exposed to a series of carefully chosen solutions; the supports are separated at various steps, producing smaller collections bearing unique chemicals. Such reactions are easier to track than those performed in solution and can yield a wide variety of products.

Infinity's pedigree is impressive. Richard Klausner, former head of the National Cancer Institute, and Eric Lander, the cofounder of genomics pioneer Millennium Pharmaceuticals, are scientific advisors. Steven Holtzman, Millennium's longtime chief financial officer, says he left to become president and CEO of Infinity because "I felt that perfecting that biological revolution required a revolution in chemistry…And I felt this platform had the best chance."

Infinity is focusing first on drugs for diabetes, inflammation, cancer and bacterial infections. "At the very least, it will be a more diverse set of compounds to test," says Brent Stockwell, a chemist at the Whitehead Institute for Biomedical Research in Cambridge, MA. "But perhaps they'll even be better." That would give drugmakers a cornucopia to rival the biologists'. —*Erika Jonietz*

JAMES YANG (ILLUSTRATION); COURTESY OF SARNOFF (VIDEO GAME)

Boeing's device can be installed in the flight deck (above) or used in portable laptop form.

NETWORKED COCKPIT

AVIATION | The industrial world may be electronically networked, but the pilot in a typical passenger jet still communicates through tinny radio voice links, pores over paper manuals to troubleshoot warning lights, and looks out the window to find the right taxiway. But this year, Chicago-based Boeing is attempting to boost safety and efficiency by bringing more computation to the skies.

Boeing calls its innovation an "electronic flight bag"—a package of advanced software and hardware in a deceptively simple-looking box built into the cockpit. The box, which has a 26-centimeter (diagonal) display, is meant to replace the pilot's briefcase full of maps and manuals, and also to provide wireless data links to ground crews and airline offices. It's largely geared toward improving safety: for example, by summoning a virtual map of an airport's taxiways, with the plane's satellite-derived location highlighted, pilots can avoid straying onto active runways. But thanks to real-time Internet connectivity via satellite, pilots will also be able to view digital weather maps of their destinations, or send requests for maintenance, speeding operations. Craig Larson, chief engineer of flight services for Boeing, says the device "makes an individual airplane a node in a larger airline and maintenance network."

Boeing expects to announce its first customer for the technology this year. Rival Airbus says it's working on a similar package of hardware and services. While initially helping pilots "get rid of a big bag of paper," says MIT aeronautics engineer Jim Kuchar, the system could ultimately become "a major step" toward a data exchange system that improves safety and reduces delays. —*David Talbot*

MAGNETIC FUTURE

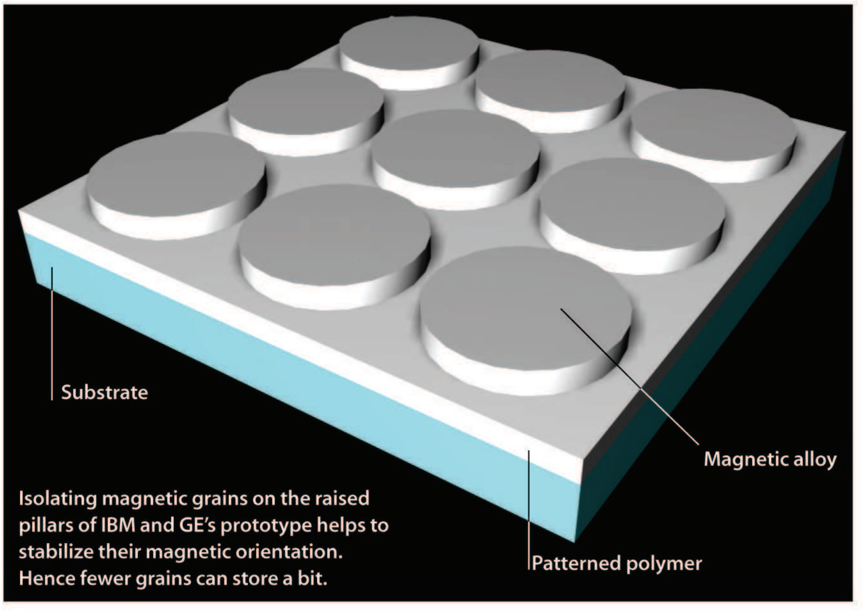
Isolating bits on a disk drive could shatter storage limits

ELECTRONICS | Every few years experts proclaim the imminent end of advances in magnetic media, the technology behind most computer data storage. But engineers keep finding new tricks to cram more data onto hard drives, such as making the magnetic grains that store bits smaller. Now even these tactics are hitting a physical limit—but that doesn't spell the end of magnetic media.

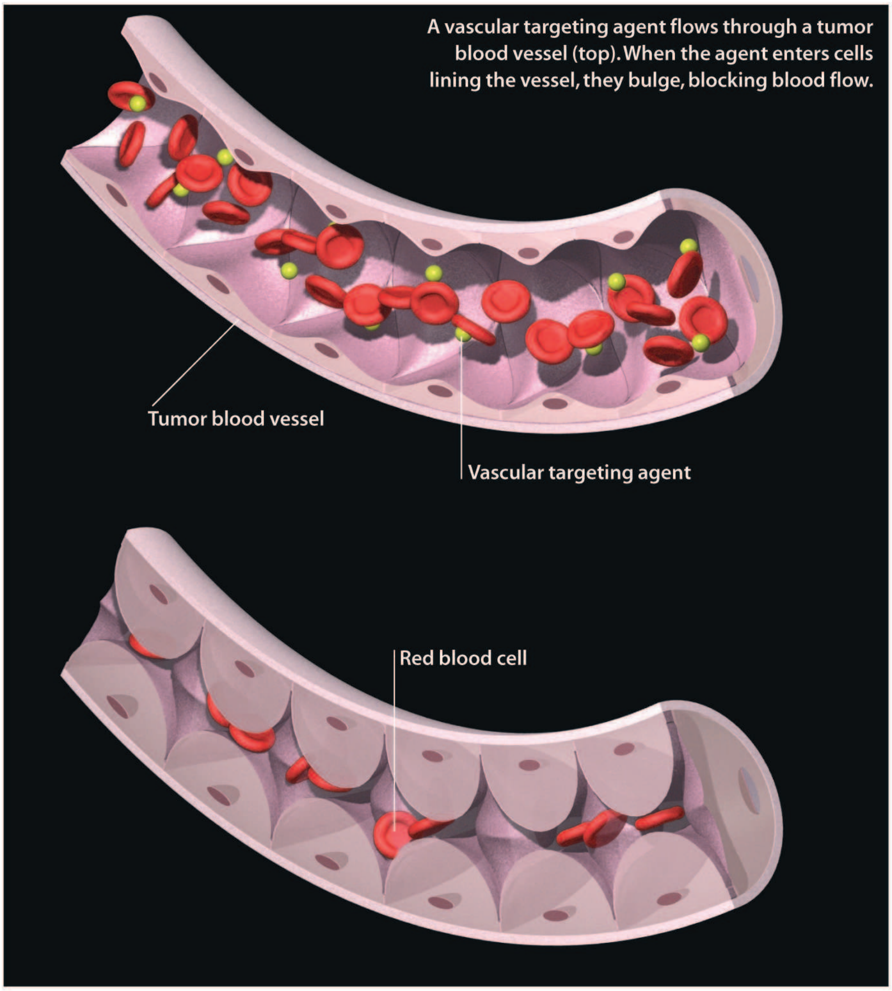
To keep increasing the data density of hard drives, researchers in a consortium that includes IBM and General Electric are working on a scheme called "patterned media," which could boost storage capacity by physically isolating a disk's magnetic grains from one another on nanoscale "islands." In today's technology, several hundred magnetic grains are needed to store a bit clearly, and if the grains become too small and densely packed, they lose their magnetic orientation. On an island, a bit might be stored stably with just one grain, allowing bits to be spaced more closely. A prototype device should be ready by 2004.

IBM has proved the concept by carving islands in magnetic alloys with a focused ion beam. And GE is developing a mass-manufacturing method, creating a polymer that can be stamped with a grid of pillars—each about 50 nanometers square and five nanometers high—and coated with a thin film of magnetic alloy. In their initial incarnation, patterned media could yield disks that hold between 30 and 40 gigabits per square centimeter, ten times the density of today's products, says Brad Reitz, GE's manager for the project. Eventually, says Bruce Terris, Reitz's counterpart at IBM, the technology might be pushed to more than 150 gigabits per square centimeter. At today's sizes, a laptop hard drive with that density could hold over a terabyte of data, and a device like Apple Computer's iPod music player could hold more than 57,000 songs—almost 30 times its current capacity.

Other university and corporate labs are also pursuing patterned magnetic-media technology. But observers say these researchers shouldn't count their terabytes until they've been tested. "Patterned media is very difficult to do," says Dave Reinsel, a storage industry analyst for Framingham, MA-based IDC. "It's a fundamental change to the way we do storage." Nevertheless, Reinsel thinks patterned-media technology may make it out of the lab and onto the market by around 2008. If it does, magnetic storage may have an attractive future after all. —*Erika Jonietz*



Isolating magnetic grains on the raised pillars of IBM and GE's prototype helps to stabilize their magnetic orientation. Hence fewer grains can store a bit.



A vascular targeting agent flows through a tumor blood vessel (top). When the agent enters cells lining the vessel, they bulge, blocking blood flow.

JOHN MACNEILL

CHOKING OFF CANCER

New drugs kill tumors from the inside out

MEDICINE | Today's cancer drugs are notorious for killing healthy cells along with cancerous ones. A new anticancer approach could offer a more precise option: kill just the tumor by choking off its blood supplies. The first drugs based on this approach are now in human trials and, if they work, could provide a virtually side-effect-free means of fighting a host of cancers.

Called vascular targeting agents or antivascular therapies, the new drugs block the blood vessels that carry oxygen and nutrients to tumors. "Basically, it starves the tumor cells to death, so you get a massive amount of tumor-cell kill," says Dai Chaplin, chief scientific officer at Watertown, MA-based Oxigene. This is in contrast to conventional chemotherapies, which kill cancer cells directly, and to another experimental approach called "anti-angiogenesis," in which drugs stop new tumor blood vessels from growing.

Oxigene, Aventis and AstraZeneca are each testing vascular targeting agents in humans. These drugs bind to a protein called tubulin, preferentially targeting the tubulin in the cells that line the interior of tumor blood vessels. Long chains of the protein normally form an internal scaffold that helps keep these cells flat. The binding disrupts the scaffolding, and "the cells become fat and podgy and obstruct the blood flow through the tumor," says vascular-targeting pioneer Phil Thorpe, a professor of pharmacology at the University of Texas Southwestern Medical Center. This effect can be seen within hours after injection of the drug.

So far, researchers have seen very few side effects in human tests, though a number of patients have felt pain in their tumors. And binding to tubulin is short-lived—on the order of hours—long enough to halt tumor blood flow but not long enough to kill normal cells, Thorpe says. "These drugs seem inherently safer than the blanket anticancer drugs that are currently available," he notes.

Thorpe and other researchers are also developing antivascular therapies that use bioengineered antibodies or other agents to target molecules found only on tumor blood-vessel cells; attached to the antibodies are chemicals that kill the cells or trigger blood clots that block the vessels. Tustin, CA-based Peregrine Pharmaceuticals has licensed Thorpe's technology and aims to begin human trials in the next year and a half.

"The work that [the researchers] are doing is very good," says Judah Folkman, a cell biologist at Harvard Medical School and a leader in anti-angiogenesis research. He says that antivascular therapies differ in key ways from the 20-odd anti-angiogenesis drugs now in clinical trials: "Anti-angiogenic therapy targets tiny microscopic vessels in a tumor," preventing the tumor from growing; "antivascular therapy targets very large vessels and works very quickly." Some researchers believe this difference will give antivascular drugs an edge in treating large, established tumors.

Ultimately, Folkman and others agree, both approaches will likely be used in combination with conventional cancer treatments—and perhaps with each other—to battle a variety of cancers. "The vascular targeting agents kill the tumors from the inside out," says Thorpe, but a rim of tumor cells survives. Those cells are the most vulnerable to existing chemotherapies and radiation treatments, and to anti-angiogenic drugs. "The whole goal is really two-part," says Folkman: reducing the harsh side effects of cancer treatment, and reducing the chance that some cancer cells will evade treatment. "That would be a big step in the next decade, and antivascular therapy will play a major role."

—*Rebecca Zacks*

INCUBATING DEFENSE TECHNOLOGY

The army grows firms that may wire the battlefield

DEFENSE | When the U.S. Army tested new wireless technology this spring at Fort Monmouth, NJ, it was also testing a new way to foster commercial development of military technologies. The ultrasecure cell phones used in the test were developed by Secureant—one tenant in a new army-funded incubator established specifically to nurture companies that could deliver information technologies for the battlefield of the future.

The Applied Communications and Information Networking project set up shop last fall. Each of the four firms sharing the project's Camden, NJ, facility is working on technology for "networked warfighting"—information sharing during the chaos of battle. The project's creators—the Army Communications and Electronics Command in Fort Monmouth, Sarnoff of Princeton, NJ, and Drexel University—hope that it will help the military out of an innovation dead end created by 50 years of reliance on big defense contractors. The U.S. Department of Defense is finding that the center of innovation in information technology has shifted dramatically, with small, private companies often setting the pace.

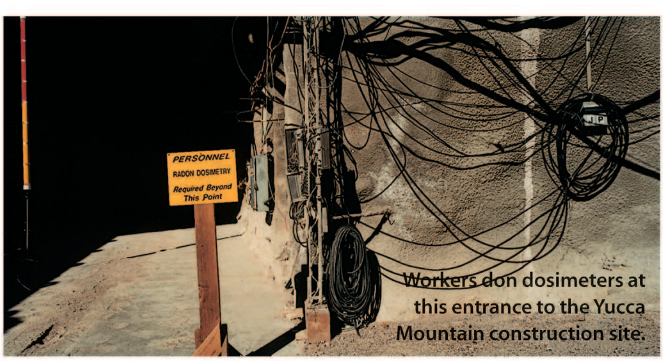
Some 900 incubators are operating in the U.S., but the Camden facility is the first devoted to defense technologies. The deal is simple: companies get office space and entrepreneurial advice, while the military gets a first look at whatever technology emerges. "This is an experiment," says entrepreneur-in-residence Lou Bucelli, who provides mentorship to the incubator's tenants. But for those tenants, it's not so much an experiment as a shot of adrenaline. Secureant, for example, had been working for three years on improving the security and range of wireless transmissions. Now the army is interested in using the company's encryption and error reduction methods to deploy soldiers farther from command posts without losing radio contact. The same technology could mean fewer civilian cell phone towers.

Secureant's cohabitants in the incubator are each targeting different defense establishment needs. InterraTech, for instance, tailors e-commerce systems to help small companies do business with the military; its software accounts for the complexities of military contracting.

The success of these enterprises is far from assured, given that the majority of startups die whether or not they started life in incubators. Still, Bucelli argues that the army project offers its startups a safer path to market. With a near-term customer in the U.S. military, as well as continued support while they adapt their products for the commercial marketplace, the companies may indeed get their technologies out of the incubator and onto the battlefield. *—Herb Brody*

NEW NUKE SOLUTION

ENERGY | Spent nuclear fuel remains dangerously radioactive for 10,000 years or more—one reason that storing it scares scientists and politicians alike. In a study funded by the U.S. Department of Energy, nuclear physicists from the University of Nevada, New Mexico's Los Alamos National Laboratory and other organizations have concluded that one possible technique for managing nuclear waste could work on an industrial scale. The technique—bombarding waste with high-speed neutrons—would reduce both the half-life of the waste's longest-lived elements, such as plutonium, and the quantity of waste that needs to be stored.

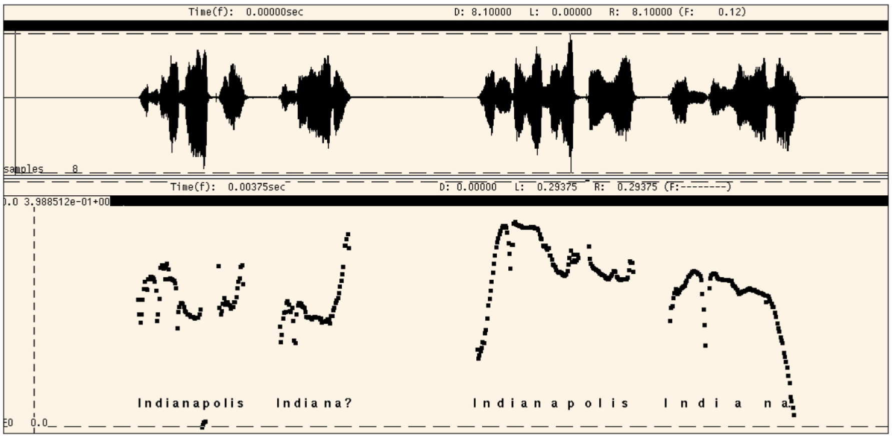


Workers don dosimeters at this entrance to the Yucca Mountain construction site.

The ultimate goal of the Advanced Accelerator Applications Program, as the study is called, is to build a demonstration unit that chemically treats spent nuclear fuel to extract plutonium and other long-lived elements—about one percent of the waste. These elements would then be placed in a particle accelerator or a special reactor and bombarded with neutrons, splitting their nuclei into elements that either aren't radioactive or decay in just decades.

The catch: a full-scale demonstration facility could take 20 years to build and cost $4 to $7 billion. But Stanford University physicist Burton Richter, chairman of an independent review board that recently endorsed the project, says the alternatives may cost even more. Even if the national repository under construction in Nevada's Yucca Mountain opened today, he notes, U.S. nuclear plants would fill it by 2015. "For nuclear power to have a future," Richter says, "we'll either need more Yucca Mountains, or a way to decrease the stuff we put there." ***—David Cameron***

JAN STALLER (NUKE); JAMES YANG (ILLUSTRATION)



Study the wave: SRI researchers use changes in loudness (top) and pitch (bottom) to reveal whether "Indianapolis, Indiana" was a question (left) or a statement (right).

COURTESY OF SRI INTERNATIONAL

PROSODY

Computers will soon hear your pain

Sometimes it's not what you say, but how you say it. That's a truism most people can relate to—but computers can't. While speech recognition software has gotten quite good at understanding words, it still can't discern punctuation like periods and commas, or choose between ambiguous sentences whose meanings depend on the speaker's emotion. That's because such software still can't make sense of the intonations, emphases and pauses—collectively known as prosody—that people intuitively use to make such distinctions.

But with more than a hundred corporate and academic research groups working on the problem, attempts at incorporating prosody into speech software are enjoying growing success. Prosody-based tools are already used for speech synthesis—to improve the naturalness of computer voices like those that recite your bank balance over the telephone. As prosody research advances, these automated systems will sound more and more natural even when speaking complex sentences.

It's in speech recognition, however, that the most critical benefits should come. Recent advances suggest that within five years, prosody software will perform tasks such as telling when a customer speaking to an automated telephone system is getting angry and respond accordingly—by, say, transferring the call to a human. "This is really cutting-edge stuff," says Michael Picheny, computer scientist and manager of the speech and language algorithms group at IBM Research in Yorktown Heights, NY. "Until the last couple of years, the quality of speech recognition was so primitive that it wasn't even worth exploring how to elicit different behaviors from machines by conveying emotional intent. First you just wanted the machine to get the words right."

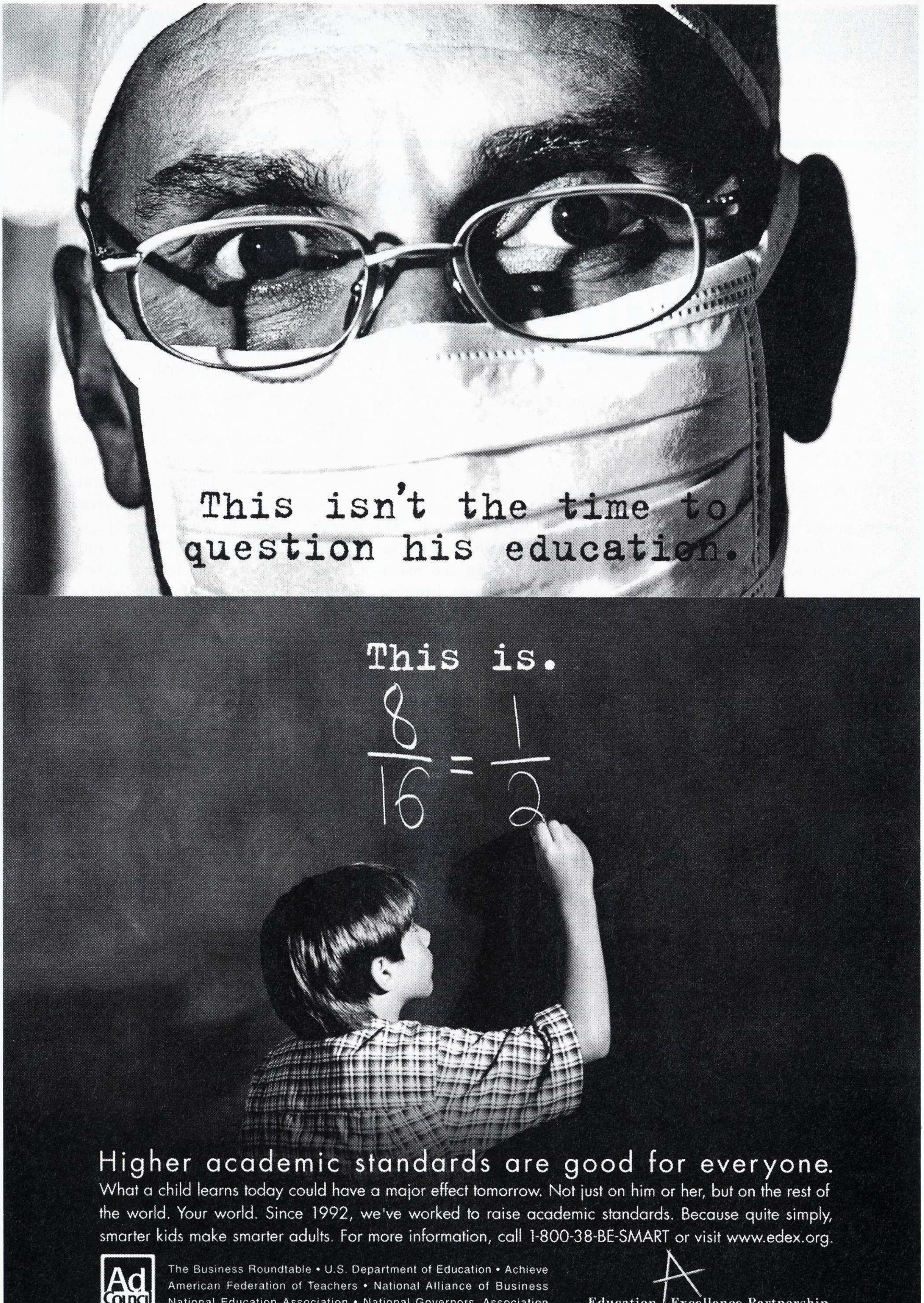
Sound waves have three basic components that prosody software can work with. The first is timing—the duration of pauses between words and sentences. Second comes pitch—more precisely, the relative change in pitch within words and sentences. Lastly, there is volume—an amplitude change indicating emphasis.

Gleaning meaning from these features is much tougher for a computer than identifying words, says Elizabeth Shriberg, a computer scientist who leads prosody research at SRI International in Menlo Park, CA. Words are a linear series of phonetic events, such as "ee" and "th." Prosodic features, by contrast, occur across words and sentences. Worse, different kinds of prosodic patterns often overlap one another; one set might reveal that a sentence was spoken calmly, a second that the sentence was a question. But researchers are beginning to map them. For example, Shriberg and her coworkers have created a template of an angry sentence: it's slower overall, has an exaggerated emphasis on key words and ends with a downward turn in pitch ("I needed this *last Tuesday* but it hasn't arrived"). Shriberg has generated prosodic models of everything from different emotional states to punctuation to "disfluencies"—shifts when people change thoughts midsentence or mumble "uh."

While SRI's tools are still research exercises, wide-scale use of prosody for speech recognition could be just over the horizon. Limited applications are already used in Chinese speech recognition software. In China, depending on inflection, the word "Ma" can mean "mom" or "horse," or indicate that the sentence was a curse, explains Xuedong Huang, a computer scientist who heads a speech technology group at Microsoft Research in Redmond, WA. "That's very dangerous," he jokes. Microsoft has already begun incorporating simple prosody into its Chinese language speech recognition software and is working to create next-generation software for Chinese and Japanese languages.

The next five years should see English-language prosodic tools for speech recognition make their first market forays. One application: companies could automatically search recorded customer service telephone databases, find the angry calls and study what went wrong. Another possibility: identifying punctuation, so doctors speaking into dictation systems won't have to say "period."

But it will take at least ten years, says SRI's Shriberg, before any computer can begin to do what people do every day—completely decode a conversation with all its inflection, while filtering out background noises. "We are trying to close the [man-machine] gap somewhat, so when humans are in short supply, or in space, or on life support, the computer will be as smart as possible," Shriberg says. For now, anyway, just don't try explaining that ambition to a computer. It won't understand your excitement. —*David Talbot*


This isn't the time to question his education.
This is.
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DECLARE E-MAIL INDEPENDENCE

This past March, I started getting dozens of e-mails from upset but resigned AT&T Broadband customers. All said more or less the same thing: their e-mail addresses were about to stop working. I had to update my address book to change the letters after the @ sign from "mediaone.net" to "attbi.com."

More than 630,000 AT&T customers were forced to make this change. They could have used the occasion to simply and inexpensively assert their electronic individuality and independence. Instead, the majority behaved like good sheep and did what they were told: moved from one mega-corporate address that they didn't own to another. Baa-a-a-a! Baa-a-a-a!

Few people realize just how much control over the increasingly pervasive medium of e-mail they have tacitly conceded. Many, for instance, think that they somehow own their e-mail addresses. Wrong! Legally and technically, the company, university or individual who owns the computer systems behind an e-mail address controls all aspects of the accounts it serves. In fact, the addresses belong to the company whose name comes after the @. (In the case of mediaone.net, AT&T relinquished the name to another Media One, an advertising agency in Sioux Falls, SD, to settle a lawsuit.)

You may think you're entitled to an e-mail address because you've religiously paid some Internet service provider your monthly subscription fee for years. That's not the case. Your provider can cancel your e-mail account for any reason and bounce your e-mail. Or it can give your username—and your e-mail!—to somebody else. Or it can lock you out of your account and read your e-mail without your permission. (Having owned a small Internet service provider since 1995, I know well the responsibilities and dilemmas that come with this awesome power.)

In one case that I know, a person had used the same corporate e-mail address for both his business and personal communications for several years. This seemed reasonable—after all, he had cofounded the company. But he was fired in a power struggle, and the new president decided to read all the personal e-mail that kept trickling into this fellow's account. This was all perfectly legal: the company's computer policy explicitly said that e-mail messages were the property of the business and could be read by management for any reason. In another instance, a friend lost her Internet account after she got into an argument with the firm providing her Internet service. But rather than canceling her username, the provider simply changed her password. Mail to her old address accumulated for months, unread. People who send messages to her old address still get the response that her mailbox is full.

E-mail is tremendously different from the two other addressing systems that we use routinely—postal addresses and telephone numbers. Because postal addresses are covered by a huge body of regulations and laws, and because most are linked to physical locations, they work pretty much the way we expect them to. If you move, the U.S. Postal Service will forward mail to your new residence. It will not, however, forward the mail from your old place of work to a new one, even if you ask extra nicely; that's the job of the business.

Telephone numbers, on the other hand, are increasingly regarded by law as the property of the person or organization to which they connect. In fact, the 1996 U.S. Telecommunications Act specifically requires telephone companies to create a framework for telephone number portability, so that businesses and residences can switch phone service providers without losing their phone numbers.

But the Telecommunications Act was silent on the subject of e-mail addresses. The U.S. Congress didn't think to mandate e-mail address portability. It didn't even mandate the next best thing—e-mail forwarding. If you are an America Online user and decide that you want to switch to another Internet provider, the only thing you can do is send mail to all of your correspondents, telling them of your new address. AOL will not forward your mail.

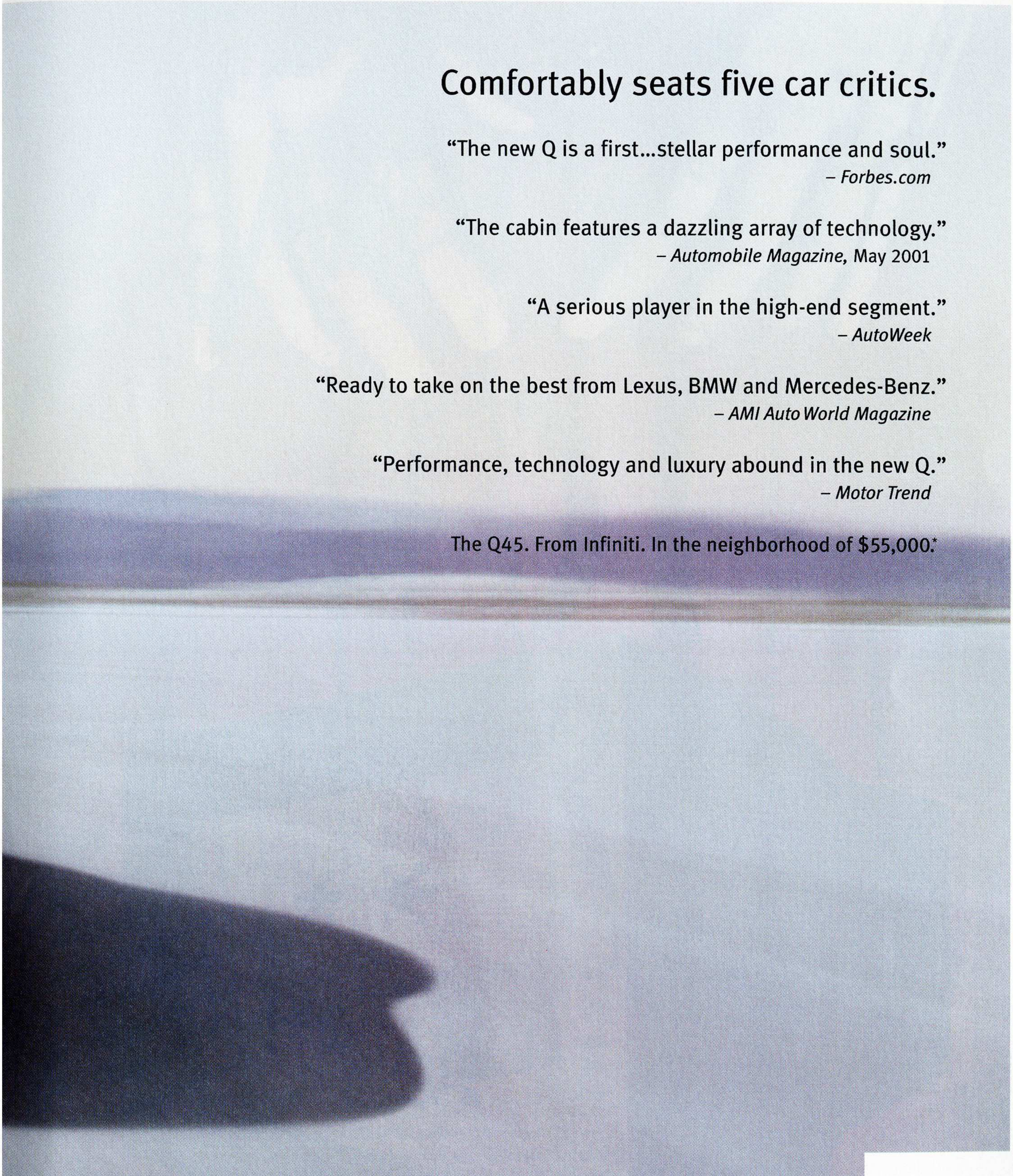
Most e-mail users behave like sheep, moving from one corporate address that they don't own to another. But there's a simple solution to address portability: get your own domain name.

What's so distressing about this state of affairs is that there is a simple solution to the problem of e-mail address portability. Every person and every company should get a unique domain name.

Recall that the domain name is the part of the e-mail address after the @ sign. Years ago there were attempts by the Internet's inventors to limit the proliferation of names for technical reasons—people were worried that there might be too many of them. As a result, domain names were made expensive. But those days are long gone. Nowadays you can get your own domain name for less than $25 a year from any of a number of companies. And these names are portable—that is, you can take them with you from one Internet service provider to another.

Of course, people are taught to be sheep for a reason. Customers tied to @attbi.com or @aol.com addresses are inhibited from switching to a rival service provider—which ultimately means that the companies don't have to compete as hard. That's why neither AT&T nor AOL has worked to make it easy for customers to have their own domains.

In the 21st century, having your own domain name is simple electronic self-defense. Alas, many people find it easier to be sheep. TR


Comfortably seats five car critics.
"The new Q is a first...stellar performance and soul."
– *Forbes.com*
"The cabin features a dazzling array of technology."
– *Automobile Magazine*, May 2001
"A serious player in the high-end segment."
– *AutoWeek*
"Ready to take on the best from Lexus, BMW and Mercedes-Benz."
– *AMI Auto World Magazine*
"Performance, technology and luxury abound in the new Q."
– *Motor Trend*
The Q45. From Infiniti. In the neighborhood of $55,000.*
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FieldInfo fi = t.GetField(fieldName);object val = fi.GetValue(o);Consol
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WHY SOFT-WARE IS SO BAD

CARELESS PROGRAMMING INFLICTS APPALLING COSTS—BUT FINALLY, SOFT-WARE FIRMS ARE CON-FRONTING THE PROBLEM.

It's one of the oldest jokes on the Internet, endlessly forwarded from e-mailbox to e-mailbox. A software mogul—usually Bill Gates, but sometimes another—makes a speech. "If the automobile industry had developed like the software industry," the mogul proclaims, "we would all be driving $25 cars that get 1,000 miles to the gallon." To which an automobile executive retorts, "Yeah, and if cars were like software, they would crash twice a day for no reason, and when you called for service, they'd tell you to reinstall the engine."

The joke encapsulates one of the great puzzles of contemporary technology. In an amazingly short time, software has become critical to almost every aspect of modern life. From bank vaults to city stoplights, from telephone

BY CHARLES C. MANN | ILLUSTRATIONS BY BRIAN STAUFFER

networks to DVD players, from automobile air bags to air traffic control systems, the world around us is regulated by code. Yet much software simply doesn't work reliably: ask anyone who has watched a computer screen flush blue, wiping out hours of effort. All too often, software engineers say, code is bloated, ugly, inefficient and poorly designed; even when programs do function correctly, users find them too hard to understand. Groaning beneath the weight of bricklike manuals, bookstore shelves across the nation testify to the perduring dysfunctionality of software.

"Software's simply terrible today," says Watts S. Humphrey, a fellow of Carnegie Mellon University's Software Engineering Institute who has written several well-known books on software quality. "And it's getting worse all the time." Good software, in Humphrey's view, "is usable, reliable, defect free, cost effective and maintainable. And software now is none of those things. You can't take something out of the box and know it's going to work." Over the years, in the view of Edsger W. Dijkstra, an emeritus computer scientist at the University of Texas at Austin, the average computer user "has been served so poorly that he expects his system to crash all the time, and we witness a massive worldwide distribution of bug-ridden software for which we should be deeply ashamed."

Jim McCarthy is more generous. The founder, with his wife Michele, of a software quality training company in Woodinville, WA, McCarthy believes that "most software products have the necessary features to be worth buying and using and adopting." But, he allows, "only the extreme usefulness of software lets us tolerate its huge deficiencies." McCarthy sometimes begins talks at his school with a PowerPoint presentation. The first slide reads, "Most Software Sucks."

It is difficult to overemphasize the uniqueness of software's problems. When automotive engineers discuss the cars on the market, they don't say that vehicles today are no better than they were ten or fifteen years ago. The same is true for aeronautical engineers: nobody claims that Boeing or Airbus makes lousy planes. Nor do electrical engineers complain that chips and circuitry aren't improving. As the engineering historian Henry Petroski suggested in his 1992 book *The Evolution of Useful Things*, continual refinement is the usual rule in technology. Engineers constantly notice shortcomings in their designs and fix them little by little, a process Petroski wryly described as "form follows failure." As a result, products incrementally improve.

Software, alas, seems different. One would expect a 45-million-line program like Windows XP, Microsoft's newest operating system, to have a few bugs. And software engineering is a newer discipline than mechanical or electrical engineering; the first real programs were created only 50 years ago. But what's surprising—astonishing, in fact—is that many software engineers believe that software quality is not improving. If anything, they say, it's getting worse. It's as if the cars Detroit produced in 2002 were less reliable than those built in 1982.

As software becomes increasingly important, the potential impact of bad code will increase to match, in the view of Peter G. Neumann, a computer scientist at SRI International, a private R&D center in Menlo Park, CA. In the last 15 years alone, software defects have wrecked a European satellite launch, delayed the opening of the hugely expensive Denver airport for a year, destroyed a NASA Mars mission, killed four marines in a helicopter crash, induced a U.S. Navy ship to destroy a civilian airliner, and shut down ambulance systems in London, leading to as many as 30 deaths. And because of our growing dependence on the Net, Neumann says, "We're much worse off than we were five years ago. The risks are worse and the defenses are not as good. We're going backwards—and that's a scary thing."

Some software companies are responding to these criticisms by revamping their procedures; Microsoft, stung by charges that its products are buggy, is publicly leading the way. Yet problems with software quality have endured so long, and seem so intractably embedded in software culture, that some coders are beginning to think the unthinkable. To their own amazement, these people have found themselves wondering if the real problem with software is that not enough lawyers are involved.

"THE ATTITUDE TODAY IS THAT YOU CAN WRITE ANY SLOPPY PIECE OF CODE AND THE COMPILER WILL RUN DIAGNOSTICS."

A LACK OF LOGIC

Microsoft released Windows XP on Oct. 25, 2001. That same day, in what may be a record, the company posted *18 megabytes* of patches on its Web site: bug fixes, compatibility updates, and enhancements. Two patches fixed important security holes. Or rather, one of them did; the other patch didn't work. Microsoft advised (and still advises) users to back up critical files before installing the patches. Buyers of the home version of Windows XP, however, discovered that the system provided no way to restore these backup files if things went awry. As Microsoft's online Knowledge Base blandly explained, the special backup floppy disks created by Windows XP Home "do not work with Windows XP Home."

Such slip-ups, critics say, are merely surface lapses—signs that the software's developers were too rushed or too careless to fix obvious defects. The real problems lie in software's basic design, according to R. A. Downes of Radsoft, a software consulting firm. Or rather, its *lack* of design. Microsoft's popular Visual Studio programming software is an example, to Downes's way of thinking. Simply placing the cursor over the Visual Studio window, Downes has found, invisibly barrages the central processing unit with thousands of unnecessary messages, even though the program is not doing anything. "It's cataclysmic….It's total chaos," he complains.

The issue, in the view of Dan Wallach, a computer scientist at Rice University, is not the pointless churning of the processor—after all, he notes, "processing power is cheap." Nor is Microsoft software especially flawed; critics often employ the company's products as examples more because they are familiar than because they are unusually bad. Instead, in Wallach's view, the blooming, buzzing confusion in Visual Studio and so many other programs betrays how the techniques for writing software have failed to keep up with the explosive increase in its complexity.

Programmers write code in languages such as Java, C and C++, which can be read by human beings. Specialized programs

known as "compilers" transform this code into the strings of ones and zeroes used by computers. Importantly, compilers refuse to compile code with obvious problems—they spit out error messages instead. Until the 1970s, compilers sat on large mainframes that were often booked days or weeks in advance. Not wanting errors to cause delay, coders—who in the early days tended to be trained as mathematicians or physicists—stayed late in their offices exhaustively checking their work. Writing software was much like writing scientific papers. Rigor, documentation and peer-review vetting were the custom.

But as computers became widespread, attitudes changed. Instead of meticulously planning code, programmers stayed up in caffeinated all-night hacking sessions, constantly bouncing results off the compiler. Again and again, the compiler would spit back error messages; the programmers would fix the mistakes one by one until the software compiled properly. "The attitude today is that you can write any sloppy piece of code and the compiler will run diagnostics," says SRI's Neumann. "If it doesn't spit out an error message, it must be done correctly, right?"

As programs grew in size and complexity, however, the limits of this "code and fix" approach became evident. On average, professional coders make 100 to 150 errors in every thousand lines of code they write, according to a multiyear study of 13,000 programs by Humphrey of Carnegie Mellon. Using Humphrey's figures, the business operating system Windows NT 4, with its 16 million lines of code, would thus have been written with about two million mistakes. Most would have been too small to have any effect, but some—many thousands—would have caused serious problems.

Naturally, Microsoft exhaustively tested NT 4 before release, but "in almost any phase of tests you'll find less than half the defects," Humphrey says. If Microsoft had gone through four rounds of testing, an expensive and time-consuming procedure, the company would have found at most 15 out of 16 bugs. "That's going to leave you with something like five defects per thousand lines of code," Humphrey says. "Which is very low"—but the software would still have as many as 80,000 errors.

Software engineers know that their code is often riddled with lacunae, and they have long been searching for new technologies to prevent them. To manage increasingly distended projects like Windows, for example, they have developed a variety of techniques, of which perhaps the best known is component-based design. Just as houses are built with standardized two-by-fours and electrical fittings, component-based programs are built out of modular, interchangeable elements: an example is the nearly identical menu bar atop every Windows or Macintosh program. Such standardized components, according to Wallach, are not only good engineering practice, they are "the only way you can make something the size of Microsoft Office work at all." Microsoft, he says, was an early, aggressive promoter of this approach—"it's the single best engineering decision they ever made."

Unfortunately, critics say, the components are often glued together with no real central plan—as if contractors tried to erect large structures with no blueprints. Incredibly, Humphrey says, the design for large software projects is sometimes "nothing but a couple bubbles on the back of an envelope." Worse, for marketing reasons companies wire as many features as possible into new software, counteracting the benefits of modular con-

First Aid for Faulty Code

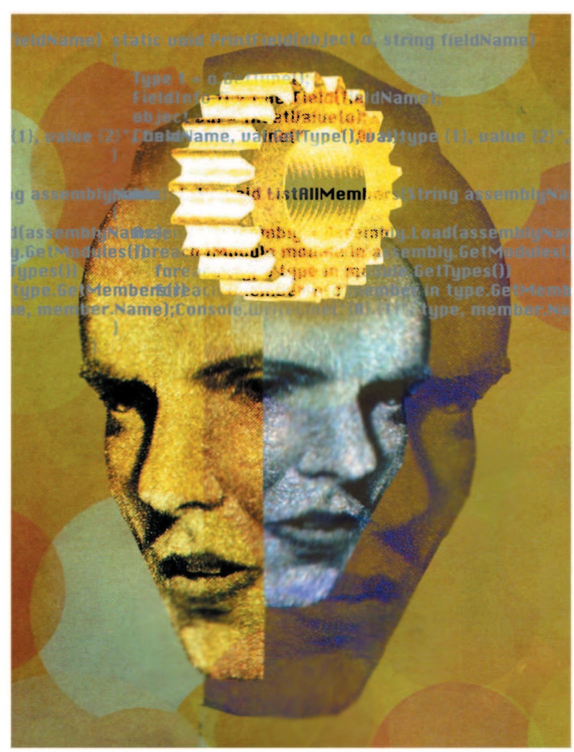
Software quality has been so bad for so long, some engineers argue, that the only solutions are litigation and legislation. More optimistic observers believe that industry is slowly beginning to adopt new practices and technological tools for making better software. Among them:

Perspective-based review. Engineers who develop code don't look at software in the same way as the system administrators who maintain it, the marketers who sell it, or the end users who put it to work. Yet, says Steve McConnell of Construx Software, development teams rarely account for these diverse perspectives. Involving colleagues like business managers, administrators, customer support agents and user interface experts in software design meetings "is obvious when you think of it, but hardly used at all," McConnell says.

Shared vision. Incredibly, the purpose of new software is often not clearly spelled out before programmers begin writing it. Indeed, it often changes in midstream as marketers come up with wish lists, with predictably bad results. According to software quality trainers Jim and Michele McCarthy, one of the keys to improving software is for all parties to reach an agreement in advance on what they're doing—"a single, explicit, universally accepted focus."

Correct by construction. Some languages, such as Ada, are designed so that programmers simply cannot commit certain mistakes. Under the Kestrel Institute's "correct by construction" approach, programmers carefully design and assemble software modules using special programming tools that prevent errors such as buffer overflows. Similarly, recent improvements in Java compilers have helped automate the process of weeding out common problems in Java code.

Tracking revisions. According to Amitabh Srivastava of Microsoft, improvements will also come from new tools that meticulously tally changes in software code, allowing testers to focus on heavily rewritten sections that may contain more errors. These and other similar changes, he says, will reverse the now prevalent approach of slapping components together by inspiration in offices full of pizza boxes and Mountain Dew.



struction. The most widespread example is Windows itself, which Bill Gates testified in an April session of the Microsoft antitrust trial simply would not function if customers removed individual components such as browsers, file managers or e-mail programs. "That's an incredible claim," says Neumann. "It means there's no structure or architecture or rhyme or reason in the way they've built those systems, other than to make them as bundled as possible, so that if you remove any part it will all fail."

The inadequate design in the final products, critics argue, reflects inadequate planning in the process of creating them. According to a study by the Standish Group, a consulting firm in West Yarmouth, MA, U.S. commercial software projects are so poorly planned and managed that in 2000 almost a quarter were canceled outright, creating no final product. The canceled projects cost firms $67 billion; overruns on other projects racked up another $21 billion. But because "code and fix" leads to such extensive, costly rounds of testing, even successful projects can be wildly inefficient. Incredibly, software projects often devote *80 percent* of their budgets to repairing flaws they themselves produced—a figure that does not include the even more costly process of furnishing product support and developing patches for problems found after release.

"System testing goes on for almost half the process," Humphrey says. And even when "they finally get it to work, there's still no design." In consequence, the software can't be updated or improved with any assurance that the updates or improvements won't introduce major faults. "That's the way software is designed and built everywhere—it's that way in spaceships, for God's sake."

IS SOFTWARE A SPECIAL CASE?

The potential risks of bad software were grimly illustrated between 1985 and 1987, when a computer-controlled radiation therapy machine manufactured by the government-backed Atomic Energy of Canada massively overdosed patients in the United States and Canada, killing at least three. In an exhaustive examination, Nancy Leveson, now an MIT computer scientist, assigned much of the blame to the manufacturer's inadequate software-engineering practices. Because the program used to set radiation intensity was not designed or tested carefully, simple typing errors triggered lethal blasts.

Despite this tragic experience, similar machines running software made by Multidata Systems International, of St. Louis, massively overdosed patients in Panama in 2000 and 2001, leading to eight more deaths. A team from the International Atomic Energy Agency attributed the deaths to "the entering of data" in a way programmers had not anticipated. As Leveson notes, simple data-entry errors should not have lethal consequences. So this failure, too, may be due to inadequate software.

Programming experts tend to agree that such disasters are distressingly common. Consider the Mars Climate Orbiter and the Polar Lander, both destroyed in 1999 by familiar, readily prevented coding errors. But some argue that software simply cannot be judged, measured and improved in the same way as other engineering products. "It's just a fact that there are things that other engineers can do that we can't do," says Shari Pfleeger, a senior researcher at the Rand think tank in Washington, DC, and author of the 1998 volume *Software Engineering: Theory and Practice*. If a bridge survives a 500-kilogram weight and a 50,000-kilogram weight, Pfleeger notes, engineers can assume that it will bear all the values between. With software, she says, "I can't make that assumption—I can't interpolate."

Moreover, software makers labor under extraordinary demands. Ford and General Motors have been manufacturing the same product—a four-wheeled box with an internal-combustion engine—for decades. In consequence, says Charles H. Connell, former principal engineer of Lotus Development (now part of IBM), they have been able to improve their products incrementally. But software companies are constantly asked to create products—Web browsers in the early 1990s, new cell phone interfaces today—unlike anything seen before. "It's like a car manufacturer saying, 'This year we're going to make a rocket ship instead of a car,'" Connell says. "Of course they'll have problems."

THE CONSTANT DEMAND FOR NOVELTY MEANS THAT SOFTWARE IS ALWAYS IN THE BLEEDING-EDGE PHASE, WHEN PRODUCTS ARE INHERENTLY LESS RELIABLE.

"The classic dilemma in software is that people continually want more and more and more stuff," says Nathan Myhrvold, former chief technology officer of Microsoft. Unfortunately, he notes, the constant demand for novelty means that software is always "in the bleeding-edge phase," when products are inherently less reliable. In 1983, he says, Microsoft Word had only 27,000 lines of code. "Trouble is, it didn't do very much"—which customers today wouldn't accept. If Microsoft had not kept pumping up Word with new features, the product would no longer exist.

"Users are tremendously non-self-aware," Myhrvold adds. At Microsoft, he says, corporate customers often demanded that the company simultaneously add new features and stop adding new features. "Literally, I've heard it in a single breath, a single sentence. 'We're not sure why we should upgrade to this new release—it has all this stuff we don't want—and when are you going to put in these three things?' And you say, '*Whaaat?*'" Myhrvold's sardonic summary: "Software sucks because users demand it to."

HIGHER STANDARDS

In January, Bill Gates issued a call to Microsoft employees to make "reliable and secure" computing their "highest priority." In what the company billed as one of its most important initiatives in years, Gates demanded that Microsoft "dramatically reduce" the number of defects in its products. A month later, the company took the unprecedented step of suspending all new code writing for almost two months. Instead, it gathered together programmers, a thousand at a time, for mass training sessions on reliability and security. Using huge screens in a giant auditorium, company executives displayed embarrassing snippets of flawed code produced by those in the audience.

Gates's initiative was apparently inspired by the blast of criticism that engulfed Microsoft in July 2001 when a buffer overflow—a long-familiar type of error—in its Internet Information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Services Web-server software let the Code Red worm victimize thousands of its corporate clients. (In a buffer overflow, a program receives more data than expected—as if one filled in the space for a zip code with a 50-digit number. In a computer, the extra information will spill into adjacent parts of memory, corrupting or overwriting the data there, unless it is carefully blocked.) Two months later, the Nimda worm exploited other flaws in the software to attack thousands more machines.

THE LAWSUITS WILL EVENTUALLY COME. AND WHEN THE COSTS OF LITIGATION GO UP ENOUGH, COMPANIES WILL BE MOTIVATED TO BULLETPROOF THEIR CODE.

Battered by such experiences, software developers are becoming more attentive to quality. Even as Gates was rallying his troops, think tanks like the Kestrel Institute, of Palo Alto, CA, were developing "correct-by-construction" programming tool kits that almost force coders to write reliable programs *(see "First Aid for Faulty Code," p. 35)*. At Microsoft itself, according to Amitabh Srivastava, head of the firm's Programmer Productivity Research Center, coders are working with new, "higher-level" languages like C# that don't permit certain errors. And in May, Microsoft cofounded the $30 million Sustainable Computing Consortium—based at Carnegie Mellon—with NASA and 16 other firms to promote standardized ways to measure and improve software dependability. Quality control efforts can pay off handsomely: in helping Lockheed Martin revamp the software in its C130J aircraft, Praxis Critical Systems, of Bath, England, used such methods to cut development costs by 80 percent while producing software that passed stringent Federal Aviation Administration exams with "very few errors."

Critics welcome calls for excellence like those from Kestrel and Microsoft but argue that they will come to naught unless commercial software developers abandon many of their ingrained practices. "The mindset of the industry is to treat quality as secondary," says Cem Kaner, a computer scientist and lawyer at the Florida Institute of Technology. Before releasing products, companies routinely hold "bug deferral meetings" to decide which defects to fix immediately, which to fix later by forcing customers to download patches or buy upgrades, and which to forget about entirely. "Other industries get sued when they ignore known defects," Kaner says. "In software, it's standard practice. That's why you don't buy version 1.0 of a program." Exasperatingly, software vendors deliver buggy, badly designed products with incomprehensible help files—and then charge high fees for the inevitable customer service calls. In this way, amazingly, firms profit from poor engineering practices.

When engineers inside a software company choose to ignore a serious flaw, there are usually plenty of reviewers, pundits, hackers and other outsiders who will point it out. This is a good thing; as Petroski wrote in *The Evolution of Useful Things*, "a technologically savvy and understanding public is the best check on errant design." Unfortunately, companies increasingly try to discourage such public discussion. The fine print in many software licenses forbids publishing benchmark tests. When *PC Magazine* tried in 1999 to run a head-to-head comparison of Oracle and Microsoft databases, Oracle used the license terms to block it—even though the magazine had gone out of its way to assure a fair test by asking both firms to help it set up their software. To purchase Network Associates' popular McAfee VirusScan software, customers must promise not to publish reviews without prior consent from Network Associates—a condition so onerous that the State of New York sued the firm in February for creating an "illegal…restrictive covenant" that "chills free speech." (At press time, no trial date had been set.)

Even a few members of the software-is-different school believe that some programming practices must be reformed. "We don't learn from our mistakes," says Rand's Pfleeger. In 1996, for example, the French Ariane 5 rocket catastrophically failed, exploding just 40 seconds after liftoff on its maiden voyage. Its $500 million satellite payload was a total loss. According to the subsequent committee of inquiry, the accident was due to "systematic software design error"—more precisely, a buffer overflow. In most engineering fields, Pfleeger says, such disasters trigger industrywide reforms, as the collapse of the World Trade Center seems likely to do for fireproofing in construction. But in software, "there is no well-defined mechanism for investigating failures and no mechanism for ensuring that people read about them." If the French coders had been drilled, like other engineers, in the history of their own discipline, the Ariane fiasco might have been avoided.

One way or another, some computer scientists predict, software culture will change. To the surprise of many observers, the industry is relatively free of product liability lawsuits. The "I Love You" virus, for instance, spread largely because Microsoft—against the vehement warnings of security experts—designed Outlook to run programs in e-mail attachments easily. According to Computer Economics, a consulting group in Carlsbad, CA, the total cost of this decision was $8.75 billion. "It's amazing that there wasn't a blizzard of lawsuits," Wallach says.

Software firms have been able to avoid product liability litigation partly because software licenses force customers into arbitration, often on unfavorable terms, and partly because such lawsuits would be highly technical, which means that plaintiffs would need to hire costly experts to build their cases. Nonetheless, critics predict, the lawsuits will eventually come. And when the costs of litigation go up enough, companies will be motivated to bulletproof their code. The downside of quality enforcement through class action lawsuits, of course, is that groundless litigation can extort undeserved settlements. But as Wallach says, "it just might be a bad idea whose time has come."

In fact, a growing number of software engineers believe that computers have become so essential to daily life that society will eventually be unwilling to keep giving software firms a free legal pass. "It's either going to be a big product liability suit, or the government will come in and regulate the industry," says Jeffrey Voas, chief scientist of Cigital Labs, a software-testing firm in Dulles, VA. "Something's going to give. It won't be pretty, but once companies have a gun to their head, they'll figure out a way to improve their code." TR

BY PETER FAIRLEY

PHOTOGRAPHS BY MISHA GRAVENOR

WIND POWER FOR PENNIES

A LIGHTWEIGHT WIND TURBINE IS FINALLY ON THE HORIZON—AND IT MIGHT JUST BE THE BREAKTHROUGH NEEDED TO GIVE FOSSIL FUELS A RUN FOR THEIR MONEY.

Blown away: Bob Thresher, director of the National Wind Technology Center in Rocky Flats, CO, says this hinged-blade turbine could slash wind power costs.

The newest wind turbine standing at Rocky Flats in Colorado, the U.S. Department of Energy's proving ground for wind power technologies, looks much like any other apparatus for capturing energy from wind: a boxy turbine sits atop a steel tower that sprouts two propeller blades stretching a combined 40 meters—almost half the length of a football field. Wind rushes by, blades rotate, and electricity flows. But there's a key difference. This prototype has flexible, hinged blades; in strong winds, they bend back slightly while spinning. The bending is barely perceptible to a casual observer, but it's a radical departure from how existing wind turbines work—and it just may change the fate of wind power.

Indeed, the success of the prototype at Rocky Flats comes at a crucial moment in the evolution of wind power. Wind-driven generators are still a niche technology—producing less than one percent of U.S. electricity. But last year, 1,700 megawatts' worth of new wind capacity was installed in the United States—enough to power 500,000 houses—nearly doubling the nation's wind power capacity. And more is on the way. Manufacturers have reduced the cost of heavy-duty wind turbines fourfold since 1980, and these gargantuan machines are now reliable and efficient enough to be built offshore. An 80-turbine, $245 million wind farm under construction off the Danish coast will be the world's largest, and developers are beginning to colonize German, Dutch and British waters, too. In North America, speculators envision massive offshore wind farms near British Columbia and Nantucket, MA.

But there is still a black cloud hovering over this seemingly sunny scenario. Wind turbines remain expensive to build—often prohibitively so. On average, it costs about $1 million per megawatt to construct a wind turbine farm, compared to about $600,000 per megawatt for a conventional gas-fired power plant; in the economic calculations of power companies, the fact that wind is free doesn't close this gap. In short, the price of building wind power must come down if it's ever to be more than a niche technology.

And that's where the prototype at Rocky Flats comes in. The flexibility in its blades will enable the turbine to be 40 percent lighter than today's industry standard but just as capable of surviving destructive storms. And that lighter weight could mean machines that are 20 to 25 percent cheaper than today's large turbines.

Earlier efforts at lighter designs were universal failures—disabled or destroyed, some within weeks, by the wind itself. Given these failures, wind experts are understandably cautious about the latest shot at a lightweight design. But most agree that lightweight wind turbines, if they work, will change the economic equation. "The question would become, 'How do you get the transmission capacity built fast enough to keep up with growth,'" says Ward Marshall, a wind power developer at Columbus, OH-based American Electric Power who is on the board of directors of the American Wind Energy Association, a trade group. "You'd have plenty of folks willing to sign up."

And, say experts, the Rocky Flats prototype—designed by Wind Turbine of Bellevue, WA—is the best hope in years for a lightweight design that will finally succeed. "I can say pretty unequivocally that this is a dramatic step in lightweight [wind turbine] technology," says Bob Thresher, director of the National Wind Technology Center at Rocky Flats. "Nobody else has built a machine that flexible and made it work."

STEADY AS SHE BLOWS

Wind turbines are like giant fans run in reverse. Instead of motor-driven blades that push the air, they use airfoils that catch the wind and crank a generator that pumps out electricity. Many of today's turbines are mammoth machines with three-bladed rotors that span 80 meters—20 meters longer than the wingspan of a Boeing 747. And therein lies the technology challenge. The enormous size is needed if commercial wind turbines are to compete economically because power production rises exponentially with blade length. But these vast structures must be rugged enough to endure gales and extreme turbulence.

In the 1970s and '80s, U.S. wind energy pioneers made the first serious efforts at fighting these forces with lightweight, flexible machines. Several startups installed thousands of such wind turbines; most were literally torn apart or disabled by gusts. Taking lightweight experimentation to the extreme, General Electric and Boeing built much larger prototypes—behemoths with 80-, 90- and even 100-meter-long blades. These also proved prone to breakdown; in some cases their blades bent back and actually struck the towers.

All told, U.S. companies and the Department of Energy spent hundreds of millions of dollars on these failed experiments in the 1980s and early 1990s. "The American model has always gravitated toward the light and the sophisticated and things that didn't work," says James Manwell, a mechanical engineer who leads the University of Massachusetts's renewable-energy research laboratory in Amherst, MA.

Into these technology doldrums sailed researchers from Denmark's Risø National Laboratory and Danish companies like Vestas Wind Systems. During the past two decades they perfected a heavy-duty version of the wind turbine—and it has become the Microsoft Windows of the wind power industry. Today, this Danish design accounts for virtually all of the electricity generated by wind worldwide. Perhaps reflecting national inclinations, these sturdy Danish designs had little of the aerodynamic flash of the earlier U.S. wind turbines; they were simply braced against the wind with heavier, thicker steel and composite materials. They were tough, rugged—and they worked.

What's more, in recent years, power electronics—digital silicon switches that massage the flow of electricity from the machine—further improved the basic design. Previously, the turbine's rotor was held to a constant rate of rotation so its alternating-current output would be in sync with the power grid; the new devices maintain the synchronization while allowing the rotor to freely speed up and slow down with the wind. "If you get a gust, the rotor can accelerate instead of just sitting there and receiving the brute force of the wind," says Manwell.

Mastering such strains enabled the Danish design to grow larger and larger. Whereas in the early 1980s a typical

commercial machine had a blade span of 12.5 meters and could produce 50 kilowatts—enough for about a dozen homes—today's biggest blades stretch 80 meters and crank out two megawatts; a single machine can power more than 500 homes.

The newest challenge facing the Danish design is finding ways for it to weather the corrosive and punishing offshore environment, where months can pass before a mechanic can safely board and fix a turbine. Vestas, for one, is equipping its turbines with sensors on each of their components to detect wear and tear, and backup systems to take over in the case of, say, a failure in the power electronics.

Vestas's approach goes to the test this summer, as Denmark's power supplier begins installing 80 Vestas machines in shallow water 14 to 20 kilometers off the Danish coastline. It will be the world's biggest offshore wind farm, powering as many as 150,000 Danish households.

WIND SHADOWS

These upgrades will make big, heavy turbines more reliable, but they don't add up to a fundamental shift in the economics of wind power. Nations like Denmark and Germany are prepared to pay for wind power partly because fossil fuels are so much more costly in Europe, where higher taxes cover environmental and health costs associated with burning them. (About 20 percent of Denmark's power comes from wind.) But for wind power to be truly cost competitive with fossil fuels in the United States, the technology must change.

What makes Wind Turbine's Rocky Flats design such a departure is not only its hinged blades, but also their downwind orientation. The Danish design faces the blades into the wind and makes the blades heavy so they won't bend back and slam into the tower. The Wind Turbine design can't face the wind—the hinged blades would hit the tower—so the rotor is positioned downwind. Finally, it uses two blades, rather than the three in the traditional design, to further reduce weight.

Advances in the computer modeling of such dangerous forces as vibration helped the design's development. Flexible blades add an extra dimension to the machine's motion; so does the fact that the whole machine can freely swivel with the wind. (Traditional designs are driven to face the wind, then locked in place.) Predicting, detecting and preventing disasters—like rapidly shifting winds that swing a rotor upwind and send its flexible blades into the tower—are control challenges even with the best design. "If you don't get that right, the machine can literally beat itself to death," says Ken Deering, Wind Turbine's vice president of engineering.

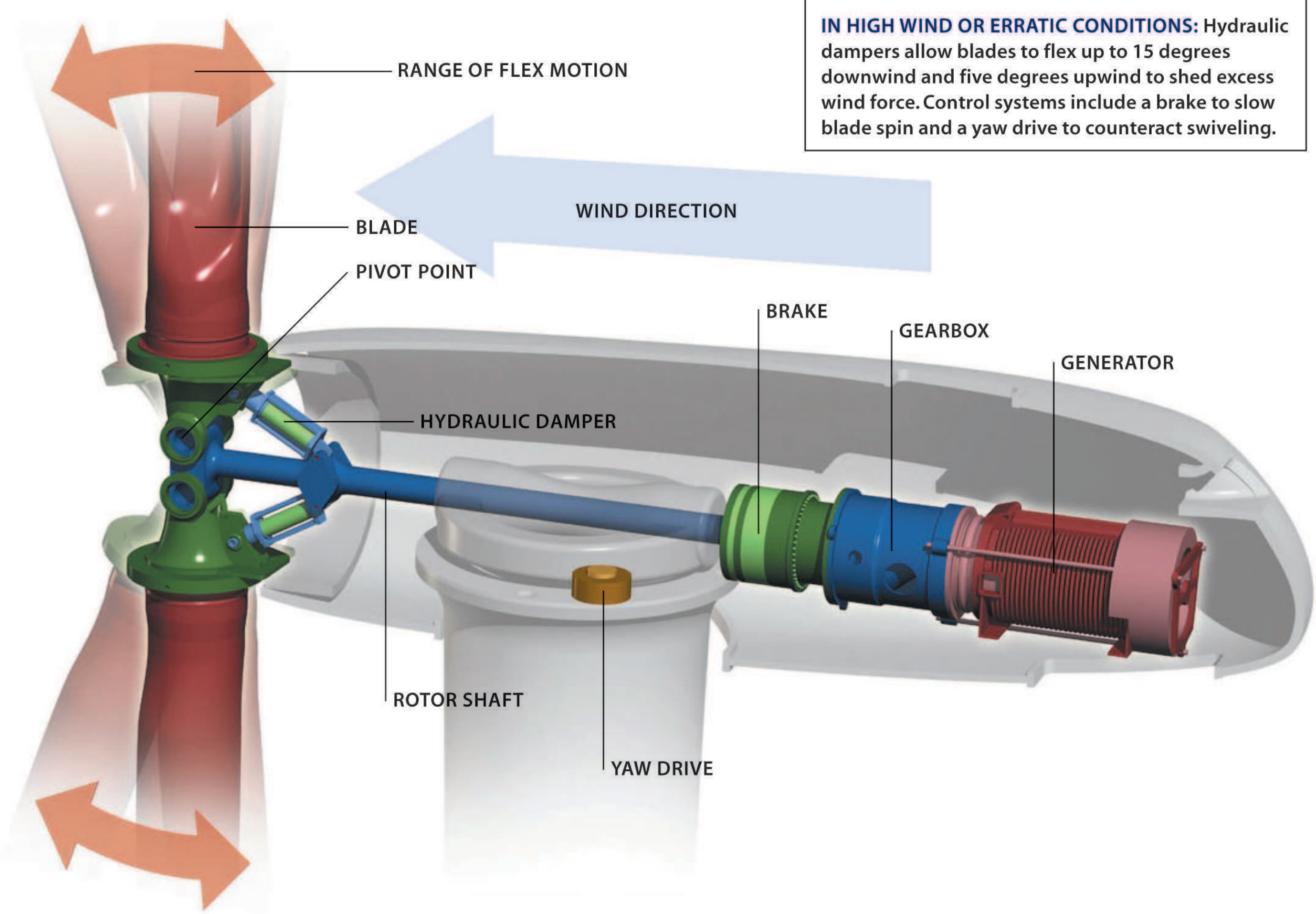
Two years ago, when Wind Turbine's prototype was erected at Rocky Flats, there were worries that this machine, too, would beat itself to death. Thresher says some of his staff feared that the machine, like its 1980s predecessors, would not long escape the scrap heap.

A Lighter, Cheaper Turbine

Hinged blades and sophisticated control systems allow the lightweight turbine designed by Wind Turbine of Bellevue,WA, to survive storms and gusts.

IN NORMAL CONDITIONS: Blades spin freely, the entire turbine swivels according to wind direction, and a gearbox amplifies blade rotation speed so a generator can produce power.

IN HIGH WIND OR ERRATIC CONDITIONS: Hydraulic dampers allow blades to flex up to 15 degrees downwind and five degrees upwind to shed excess wind force. Control systems include a brake to slow blade spin and a yaw drive to counteract swiveling.



Standing up to the wind: Thresher has seen lightweight turbine prototypes quickly destroyed by the wind itself. A new version from Wind Turbine of Bellevue, WA, though, has lasted two years.

Today, despite some minor setbacks, those doubts are fading.

Emboldened by its early success, Wind Turbine has installed, near Lancaster, CA, a second prototype, with a larger, 48-meter blade span. By the end of this year, the company expects to boost blade length on this machine to 60 meters—full commercial size. What's more, this new prototype has a thinner tower, aimed at reducing the noisy thump—known as a "wind shadow"—that can occur each time a blade whips through the area of turbulent air behind the tower. And with its lighter weight, the turbine could be mounted atop higher towers, reaching up to faster winds.

BECALMED

Whatever the advances in technology, however, the wind power industry still faces significant hurdles, starting with uncertain political support in the United States. In Europe, wind power is already a relatively easy sell. But in the United States, wind developers rely on federal tax credits to make a profit. These vital credits face chronic opposition from powerful oil and coal lobbies and often lapse. The wind power industry raced to plug in its turbines before these credits expired at the end of last year, then went dormant for the three months it took the U.S. Congress to renew them. Congress extended the credits through the end of next year, initiating what is likely to be yet another start-and-stop development cycle.

A second obstacle to broad adoption is the wind itself. It may be free and widely accessible, but it is also frustratingly inconsistent. Just ask any sailor. And this fickleness translates into intermittent power production. The more turbines get built, the more their intermittency will complicate the planning and management of large flows of power across regional and national power grids. Indeed, in west Texas, a recent boom in wind turbine construction is straining the region's transmission lines—and also producing power out of sync with local needs: wind blows during cool nights and stalls on hot days when people most need electricity.

Texas utilities are patching the problem by expanding transmission lines. But to really capture the value of wind power on a large scale, new approaches are needed to storing wind power when it's produced and releasing it when needed. The Electric Power Research Institute, a utility-funded R&D consortium in Palo Alto, CA, is conducting research on how to make better one-day-ahead wind predictions. More important, it is exploring ways to store energy when the wind is blowing. "We need to think about operating an electrical system rather than just focusing on the wind turbines," says Chuck McGowin, manager for wind power technology at the institute. Storage facilities "would allow us to use what we have more efficiently, improve the value of it."

In the northwest United States, one storage option being developed by the Portland, OR-based Bonneville Power Administration balances wind power with hydroelectric power. The idea is simple: when the wind is blowing, don't let the water pass through the hydroelectric turbines; on calm days, open up the gates. And the Tennessee Valley Authority is even experimenting with storing energy in giant fuel cells; a pilot plant is under construction in Mississippi.

Wind power faces plenty of obstacles, but there's more reason than ever to believe these obstacles will be overcome. Worries over the environmental effects of burning fossil fuels and political concerns about an overdependence on petroleum are spurring a boom in wind turbine construction. But it is advances in the technology itself, created by continued strong research efforts, that could provide the most critical impetus for increased use of wind power.

IF A LIGHTWEIGHT WIND TURBINE FINALLY SUCCEEDS, COSTS WILL DROP SO MUCH THAT THE QUESTION WILL BECOME "HOW DO YOU GET TRANSMISSION CAPACITY BUILT FAST ENOUGH TO KEEP UP WITH GROWTH?"

At Rocky Flats, four rows of research turbines—a total of a dozen machines ranging from 400-watt battery chargers to grid-ready 600-kilowatt machines—share a boulder-strewn 115-hectare plain. With the Rocky Mountains as a backdrop, their blades whup against the breezes blowing in from El Dorado Canyon to the west. At least, they do much of the time. "We have a lot of calm days, in the summer in particular, and for a testing site it's good to have a mix," Thresher says.

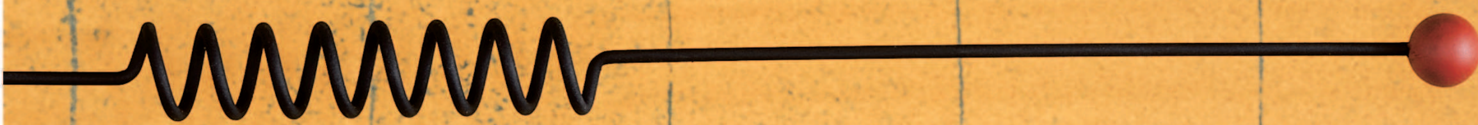
Calm days may be good for wind turbine research, but they're still among the biggest concerns haunting wind turbine commercialization. While no technology can make the wind blow, lower-cost, reliable technologies appear ready to take on its fickleness. And that could mean a wind turbine will soon sprout atop a breezy hill near you. TR

Major Players in Wind Power R&D

ORGANIZATION	R&D FOCUS
Bergey WindPower (Norman, OK)	Small (one-kilowatt to 50-kilowatt) turbines for distributed-power applications
General Electric Wind Energy (Atlanta, GA)	Improving existing large, heavy design
Mitsubishi Heavy Industries (Tokyo, Japan)	Large turbines for offshore use
National Wind Technology Center (Rocky Flats, CO)	Cost-effective turbines for moderate-wind sites
Pfleiderer Wind Energy (Neumarkt, Germany)	Simplifying gearbox with permanent-magnet generators
Risø National Laboratory (Ringkobing, Denmark)	Improving existing large, heavy design; testing of small-scale, lightweight designs
Vestas Wind Systems (Roskilde, Denmark)	Improving existing large, heavy design
Wind Turbine (Bellevue, WA)	Large, lightweight flexible turbines


TALK
PLAY
END

THE WIRELESS ARCADE



DESPITE PUNY SCREENS, PRIMITIVE TO NONEXISTENT GRAPHICS AND CONFLICTING STANDARDS, CELL PHONES AND OTHER WIRELESS HANDHELD DEVICES ARE THE HOTTEST ELECTRONIC PLAYSPACE AROUND.

BY DAVID KUSHNER • illustration by dan winters and gary tannhauser

It’s game time.

Across the rainy streets of San Jose, CA, scruffy guys with laminated badges flapping on their T-shirts scurry into the city’s convention center. The occasion is the annual Game Developer’s Conference: Mecca for the programmers, artists and technological dreamers who design and code virtual worlds. The annual event is always the place to be for anyone who’s anyone in this multibillion-dollar industry. But on this Saturday morning, the buzz is even greater than usual. After a few days discussing vector units, quaternions and 3-D fluid simulation, they’re racing to talk about something truly heady, the birth of a new medium: wireless games.

Inside the conference room, a standing-room-only crowd has assembled for the “Wireless Game Summit,” a marathon exploration of the first new gaming platform in three decades. Among the development companies attending is one launched by the legendary John Romero. Way back in the 20th century, Romero was cocreator of three fast-action video games that radically transformed the industry. Romero’s violent “first-person shooters”—Wolfenstein 3-D, Doom and Quake—let the player see through the eyes of a weapons-wielding character. With their mesmerizing 3-D graphics and over-the-Internet competition, these three games rapidly became among the bestselling offerings in video game history. Now Romero has started Monkeystone Games in Quinlan, TX, to focus on what he thinks is the next great unconquered space for gaming. “Everyone has a cell phone,” he says, “and everyone’s going to want to play games.”

Wireless games are played on Internet-enabled portable devices such as personal digital assistants and, particularly, cell phones. Though most of us are now familiar with the idea of getting driving directions or surfing the Web on a cell phone, the real killer app of wireless devices is games. Primitive-looking wireless games have already gained enormous popularity overseas. And bolstered by new software tools that allow game creators to deliver robust, colorful images, and by the emergence of third-generation, or 3G, cellular networks, wireless games may be on the verge of commercial success. The New York-based market research firm Datamonitor projects that by 2005, 80 percent of all wireless users in the United States and Western Europe—200 million people—will at least occasionally play games on their handhelds. In that period, the wireless-games market will zoom from less than $1 million per year to $6 billion, if the rosier estimates are to be believed.

This latest wrinkle in gaming has been a long time coming. Computer games were born in 1962 when MIT programmers hacked together an intergalactic simulation called Spacewar for a PDP-1 mainframe. Arcade games were hatched nine years later, when Nolan Bushnell engineered a coin-operated spinoff called Computer Space—and, one year later, Pong. The first home game consoles hit the market in 1972. Though today’s games have achieved leaps in power and sophistication—from the massively multiplayer online world of EverQuest for the PC to the stunning graphical realism of Halo for the Microsoft Xbox—they essentially rely on machines that have existed for years. There hasn’t been a new game platform since the 1970s.

Play ball!: Millions of cell phone users are taking game breaks, adding a new dimension to time-wasting.

COURTESY OF SPRINT PCS

the waiting game

Everybody waits: for school to let out, for planes to arrive, for dentists to see us. To the wireless-gaming industry, these unoccupied interludes in an average day are opportunities—minutes waiting to be killed with their creations. "There are plenty of time-saving applications," says Paul Goode, entertainment platforms group manager for Motorola. "We're working on the time-wasting ones."

There's a reason for this strong corporate interest. An estimated 60 percent of Americans play video games regularly, according to the Washington, DC-based Interactive Digital Software Association. That adds up to 145 million people, including 62 million women. Even the president of the United States confesses to daily bouts of digital solitaire. Despite the dot-com crash, U.S. sales of video games—buoyed by competition between the Sony PlayStation 2 and new home consoles from Microsoft (Xbox) and Nintendo (GameCube)—reached a record $9.4 billion last year. Americans spent more money on games than on movie tickets. Stereotypes aside, the average gamer isn't a pimply teenager, either: he's a 28-year-old adult.

ADULTS HAVE BEEN LEFT OUT OF A SIZABLE PIECE OF THE GAMES REVOLUTION; THEY AREN'T LIKELY TO MAKE ROOM IN THEIR BRIEFCASES FOR A GAME BOY. HANDHELD DEVICES HAVE AT LEAST THE VENEER OF BUSINESS UTILITY.

Thing is, adults have been largely left out of a sizable piece of this revolution. Nintendo has sold more than 100 million units of its hot handheld platform, the Game Boy. But not, by and large, to adults. The reason? It's a toy, and adults need to act like adults. They aren't likely to make room in their briefcases for a Game Boy; if they do, they're certainly not encouraged to whip out a fuchsia-colored hunk of plastic for a round of Pokémon. Cell phones and personal digital assistants have at least the veneer of business utility.

Enter wireless games—handheld games for grownups. Now cell phones can be toys disguised as tools. You punch up a "games" option on the phone, which connects to a server operated by your wireless carrier or a game publisher. The server transmits the data needed to turn the tiny screen into a playpen. Server-based games allow for frequently updated content and relieve the player of the need to carry game discs or cartridges. The server can also relay data between different players in real time, allowing for multiplayer competition: why play paintball by yourself when you could compete against someone in Japan, live?

Indeed, Japan is the model for a wireless-entertainment culture. NTT DoCoMo, that country's largest wireless company, has surprised and transformed the nation with a service called "i-mode," which allows subscribers to access games and other online entertainment wirelessly. The i-mode service requires a special cell phone with a slightly larger than ordinary screen (typically three by four centimeters) plus circuitry and software built in to handle the proprietary i-mode protocol. Users can access only the few thousand Web sites that have been modified to meet i-mode's technical specifications. But there's no dialing-up—an i-mode phone is "always on" the Net.

I-mode is phenomenally popular, engendering a "thumb culture" of 30 million subscribers—an estimated 80 percent of people worldwide who currently use wireless devices to connect to the Net. "We're all looking at DoCoMo," says Paul Palmieri, director of business development for Verizon Wireless. "Clearly the biggest category within the content is on the game side."

the lure of the simple

I-mode games offer nothing like the whiz-bang explosions of a typical video game. The most popular game, for example, is Fisupeli—virtual fishing. Like most i-mode titles, it is text-based—no graphics at all. To begin, a player types "fisu" on the phone. A message appears on the screen describing the fishing environment. The player taps keys to select lures and rods—choices that will, ultimately, determine the chances of success at catching various kinds of fish. Simple? Yes, but as seemingly timeless and compelling as a good round of Go Fish.

Given Fisupeli's sparse graphics, one lesson U.S. game companies are taking from the i-mode phenomenon is that adult players of wireless games don't need the bells and whistles that kids go for. On the contrary, adult gamers prefer simpler games. Take an offering from Los Angeles-based Jamdat Mobile called Gladiator, which has enticed more than 1.1 million people to spend some 15 million minutes competing against each other over wireless networks. That averages out to less than 15 minutes per player; people play in short busts.

Gladiator's popularity shows how compelling a primitive-looking game can be. The screen displays two combatants—you and your gladiatorial opponent. You manipulate a cursor to choose where to put up your shield and where to strike out. These choices are then sent over the wireless network, which compares them with your opponent's, calculates the results and relays back the score. It isn't realism or beauty that's driving the success of Gladiator—it's simple competition and distraction. "Developers were making better-looking games on the PDP-1 in the 1960s," admits Jamdat Mobile CEO Mitch Lasky.

Though Gladiator shares the simple structure of the i-mode games, it occupies a parallel universe. Playing it requires a handset compatible with a completely different standard, known as the wireless application protocol (often referred to by its acronym, WAP). This protocol has the disadvantage of not offering i-mode's always-on connection. Unlike i-mode, however, it works on a wide assortment of phones.

Even more widespread are lower-tech games based on a method of wireless text communication called the short-message service, or SMS. This service allows people to exchange brief text notes, generally less than 160 characters long, by typing into their cell phones or other handheld wireless devices. Already widely used in Europe, text messaging is starting to catch on rapidly in the United States *(see "Message in a Bottleneck,"* TR *January/February 2002)*. And it turns out to be well suited for gaming.

In China, for instance, a simple trivia game called Intelligence Quotient Quiz is credited with expanding the clientele of

the wireless firm Linktone 20-fold in its first month. And last September, when Bell Mobility in Canada introduced a short-message service version of the popular game show *Who Wants to Be a Millionaire*, the game was played more than 500,000 times during the first week. Games now account for more than half of the Internet traffic on the Bell Mobility wireless network. That's an even higher percentage than in Japan, where about a quarter of i-mode users seek entertainment and games. The massive popularity of these graphically simple games shows that an addictive round of trivia can be just as riveting as fancy color images of explosions and mayhem.

While the short-message service is popular in Europe and Asia, it is new in the U.S. The same goes for the wireless application protocol—available on only about one of every ten phones nationwide. Given the U.S. appetite for Millionaire-style entertainment, it and similar games will almost certainly hit these shores as wireless gaming infiltrates U.S. culture.

But that, code warriors at the San Jose conference proclaimed, is only the beginning.

the wireless doom years

Think of Gladiator and Millionaire as phase one of the mobile-game evolution—analogous to the beginnings of computer games, with their chunky-looking graphics. They represent, in effect, the Pong years. Now we're about to witness the start of phase two, to be ushered in by the deployment of newfangled hardware and game development software later this year. These will be the Doom years of wireless gaming.

This transition will occur in large part due to the advent of two new software platforms designed to make it easier for developers to create games for multiple devices, yielding a wider selection of games. One is a wireless variant of the language that powers much of the Web—Sun Microsystems' Java. The Java variant (known in the business as J2ME—for Java 2, micro edition) is now a feature on 15 million handsets and is expected to be standard on nearly all mobile phones by 2006. The other is San Diego-based Qualcomm's set of software tools called the Binary Runtime Environment for Wireless. Phones with this software—known as BREW—are already available in South Korea and will become available in the U.S. this summer from Verizon. While early wireless games are capturing a growing audience even with their low-tech look and feel, the more graphically rich games that the new platforms will make possible should appeal to a far larger audience.

Both Java and the Binary Runtime Environment offer full-color, arcadelike experiences akin to those offered by Game Boys. For example, rather than taking turns selecting moves and then waiting for the results, as in Gladiator, players might hop on the back of a tiny motorcycle and tear around an animated racetrack as an amber sun sets on the digital horizon. Or they'll play a lush round of golf as Tiger Woods.

Because games developed with these platforms are downloaded to a handset—instead of requiring users to interact with a server, as with the wireless application protocol—the chief factor limiting performance is the device's processor speed. Faster processors permit more complex games and smoother action. A typical cell phone chip today runs at around 200 megahertz—sluggish by PC standards. With wireless games, however, that isn't much of a constraint. "We made do with one megahertz on a Commodore 64," says Mikael Nerde—who oversees mobile gaming as third-party-program marketing manager for Sony Ericsson—referring to a popular home PC of the 1980s.

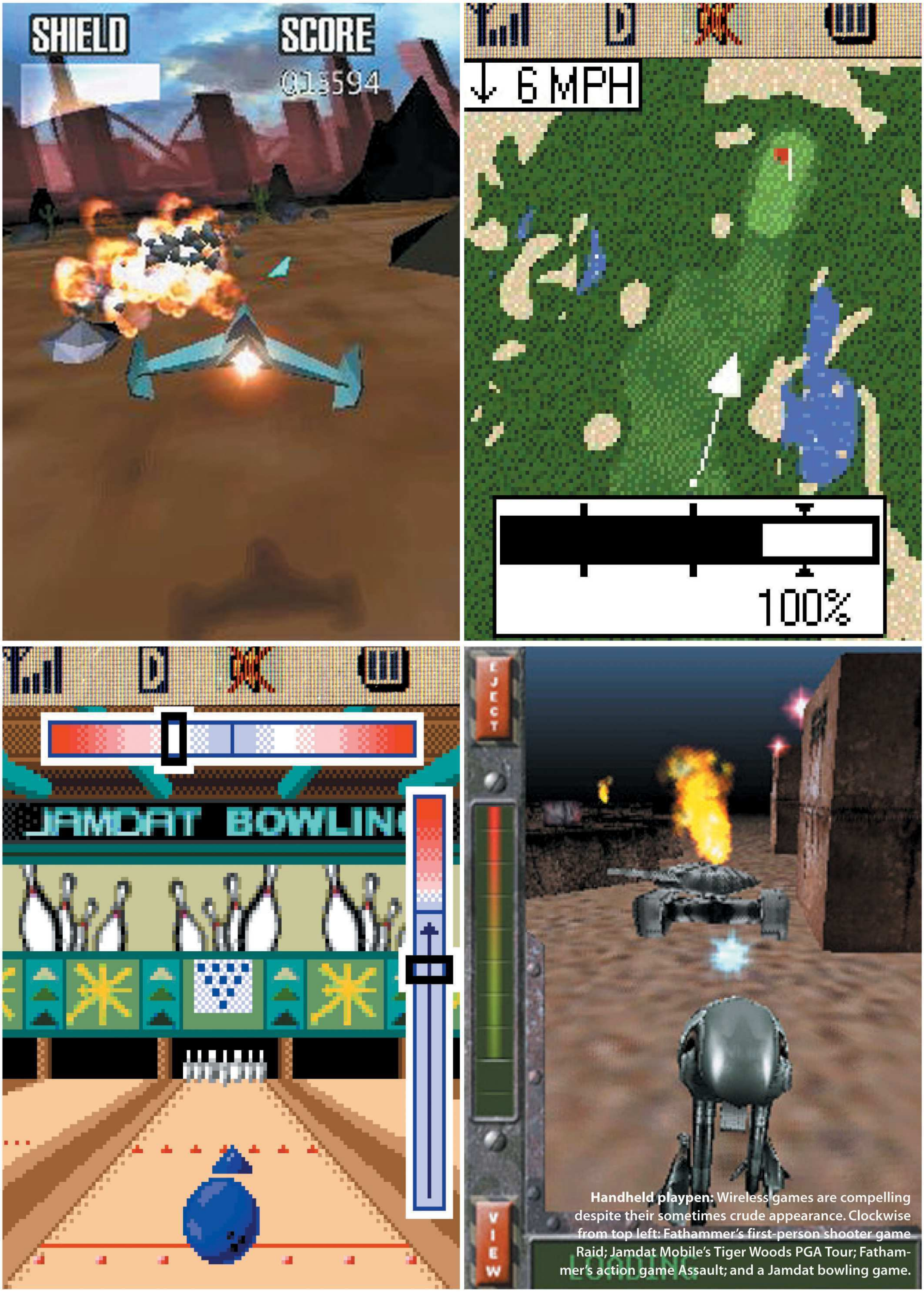
Developers can also make do—to a surprising extent—with the low bandwidth of existing wireless networks. Indeed, the new third-generation networks now becoming available in the United States and providing at least 144 kilobits per second of data delivery—ten times the capacity of today's typical wireless systems—will have only a minor influence on most mobile games. Since Gladiator transmits tiny packets of data, for example, it works fine with today's pokey wireless services. "We don't care much about bandwidth," says Jamdat's Lasky.

While higher bandwidth will not itself do much for wireless gaming, it will still have an indirect effect. That's because wireless-device makers are preparing to usher in the 3G epoch with a flood of handsets featuring larger and more colorful screens. The emergence of so-called smart phones—combination personal digital assistant and cell phone—also promises the more game-friendly interface of large color screens.

In another important development, some companies are also starting to make game-specific peripherals for mobile devices. Taiwan-based Architek, for instance, has developed a tiny cell phone joystick for players of Nokia's Snake—a hit game in which players must maneuver an ever lengthening electronic rep-

A Wireless-Game Maker Sampler

COMPANY	LOCATION/URL	MAJOR PRODUCTS	PLATFORM	NOTABLE
Digital Bridges	Dunfermline, Scotland www.digitalbridges.com	Unity	I-mode, Java, Pocket PC, wireless application protocol (WAP)	Creator of Unity content server platform
Fathammer	Morgan Hill, CA, and Helsinki, Finland www.fathammer.com	X-Forge	Linux, Pocket PC, Symbian	Built pioneering 3-D graphics engine for mobile devices
Jamdat Mobile	Los Angeles, CA www.jamdatmobile.com	Gladiator; Tiger Woods PGA Tour Wireless Golf	Java, WAP	Created one of the most successful wireless games yet—Gladiator
Monkeystone Games	Quinlan, TX www.monkeystone.com	Hyperspace Delivery Boy!; Argentum: This Is War	Pocket PC	Founded by cocreator of PC classics Doom and Quake
THQ Wireless	Calabasas Hills, CA www.thq.com	WWE Mobile Madness	Java, Binary Runtime Environment for Wireless (BREW)	Major video game developer that recently launched a wireless division



Handheld playpen: Wireless games are compelling despite their sometimes crude appearance. Clockwise from top left: Fathammer's first-person shooter game Raid; Jamdat Mobile's Tiger Woods PGA Tour; Fathammer's action game Assault; and a Jamdat bowling game.

tile before it crashes into a wall. A new version of the Binary Runtime Environment for Wireless will address another interface issue for gaming—the ability to execute certain tasks by pressing several keys at once. This capability, common on console game systems, allows for more complex character actions—such as a jump-turn-shoot maneuver.

All these technologies will converge to create a more varied gaming experience for the masses of gamers—as well as an appealing development opportunity for game creators. Calabasas Hills, CA-based THQ, for example, plans to introduce games that it says will rival in quality those it makes for the Game Boy Advance. These will include spinoffs of games based on World Wrestling Entertainment action, with animated wrestlers body-slamming each other in the ring, as well as Moto GP, a mud-slinging motocross contest. And while creation of a typical PC or console game can cost as much as $5 million and take as long as two years, the relatively graphics-poor games for mobile devices—even the next-generation ones—can be completed in six weeks for less than $50,000. There's no packaging, no retail, no muss. "It's fun to make small games again," says John Romero.

an imperfect world

The hard part still lies ahead, though. Despite the enthusiasm of the game developers and some early successes, wireless games face significant challenges. For one, the business case for wireless gaming is open to question: there's no guarantee that consumers will be willing to pay enough for games to make their creation a viable business. The London-based market research firm Ovum concluded in a recent study that few people would pay more than 50 cents a month extra to play games on their cell phones and that only a tiny fraction of cell phone users—less than two percent—would pay $10 a month.

Arcade game players who have learned to milk hours out of a few quarters will also likely find wireless gaming a far less congenial experience. Wireless distribution means that gamers essentially get punished—instead of rewarded—for their skills. "If you're successful at a network game," says Ovum analyst Roope Mokka, "you end up paying more in airtime charges because you have a longer session." What's more, the very quality that defines these games—their reliance on wireless transmission—poses sticky technical problems. No matter how advanced wireless technologies become, there's no getting around the disconnection that occurs when a player's train heads into a tunnel.

Then there is the cultural issue. Japan's affinity for the medium does not necessarily translate into U.S. acceptance. After all, i-mode has been Japan's primary means of Internet access; here, where most homes and businesses are already online, Net play is not such a novelty. Ultimately, wireless-game makers have to not only deliver the goods but compel adults to redefine the way they are entertained. Eric Goldberg, founder and chief executive of Unplugged Games, found out that's easier said than done. The New York-based developer of wireless games had to shut down his company in December despite having struck deals with Verizon, Sprint and AT&T. Goldberg reels off a list of problems with the new medium, ranging from cell phones' puny memory to the lack of peripherals. The absence of a single standard adds to doubts about the enterprise's feasibility.

Still, Goldberg and other game developers tend to see these problems as temporary growing pains rather than fundamental barriers. After all, with games comes ingenuity. A creative designer could think of a way to make such drop-outs part of a game. Some resourceful players have surprised companies by playing with their cell phones plugged into the wall to keep from missing the action when battery power flags. And in Europe, wireless gamers are embracing entirely new kinds of interactive experiences that turn games into entertainment services rather than products. It's Alive, a company in Stockholm, is pioneering a new genre it calls "pervasive gaming," which uses cell phones to lead players into real-life adventures; participants are lured to locations in the physical world where they must uncover clues and gain information. The company's first offering—BotFighters—is an assassin-style game that uses mobile positioning to alert gamers to nearby players whom they can "shoot" by typing text messages into their cell phones.

Ultimately, if mobile gaming does take off in the U.S., it could expand the current $9.4 billion gaming industry into the number one entertainment business in the country—ahead of not only movies but also music. The stakeholders aren't just the 130 million cell phone users but the biggest carriers (from Verizon to Sprint), the biggest game publishers (Electronic Arts to Sega) and the biggest manufacturers of hardware (Motorola) and software (Microsoft). "Bringing Sega content to wireless platforms is another step toward Sega.com's goal of bringing networked gaming to all devices," says Ryoichi Shiratsuchi, CEO of Sega.com and general manager of Sega Mobile Japan.

At the very least, proponents say, the new medium might do for wireless technologies what earlier games did for computers. It was in large part to satisfy game players, after all, that PC makers pushed for bigger color screens and faster processors *(see "From PlayStation to PC," TR March 2002)*. This vision animates the San Jose conference goers. "We had a revolution take place in computing years ago because of consumers' desire to have excellent entertainment on a PC," R. J. Mical, chief architect of Morgan Hill, CA, game developer Fathammer, tells those gathered at the Wireless Game Summit. "We ended up with massive machines with powerful graphics. And because of this wealth of capabilities, the Web was able to come into existence. We're going to see an equivalent revolution in mobile devices."

The crowd at the conference cheers. Game time, it seems, is just getting started. TR

NO MATTER HOW ADVANCED WIRELESS TECHNOLOGIES BECOME, THERE'S NO GETTING AROUND THE DISCONNECTION THAT OCCURS WHEN A PLAYER'S TRAIN RUNS INTO A TUNNEL, OR THE CELL PHONE'S BATTERIES DIE MID-GAME.


.com & go.
Booking flights at usairways.com has never been easier. Just a few clicks and you're on your way. You can also earn bonus Dividend Miles® while you do it. Plus, the most up-to-date flight information is always right at your fingertips. Which means, when you're ready to travel, there isn't a better place on the web to .com and go.
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PHOTOGRAPHS BY EMILY NATHAN

ANTI-BODY DRUG REVIVAL

Antibody drugs were declared dead ten years ago. Now they're biotech's hot new thing. By Gary Taubes


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In this new world of often unbridled pessimism, it's worth noting that nobody ever guaranteed you could make a living, let alone a good one, by pushing the limits of technology.

Take Nils Lonberg, for instance. Lonberg compares his company's story to Sleeping Beauty's, but his analogy is not precise. Sleeping Beauty, after all, was lucky enough to sleep through her ordeal. Lonberg and his colleagues were wide awake through theirs.

Lonberg was just a few years out of graduate school in 1989 when he signed on with GenPharm International, a company developing a class of drugs known as monoclonal antibodies—souped-up versions of the proteins produced by the immune system to fight disease. The goal was to genetically engineer a mouse with a human immune system, one that could be used to generate "fully human" monoclonal antibodies.

His timing could hardly have been worse. A series of promising monoclonal-antibody drugs to cure everything from cancer to severe infections were about to turn out to be high-profile failures. One of these, a drug called Centoxin, made by Malvern, PA-based Centocor, was projected to earn billions as a treatment for often fatal septic shock before the U.S. Food and Drug Administration declined to approve its use in 1992. The FDA decision marked the seeming demise of monoclonal antibodies and, at least for a while, of the prospects of the entire biotech industry.

"The short story," says Lonberg, "is we hunkered down." The longer story, like Sleeping Beauty's, does have a happy ending. In the past four years, Princeton, NJ-based Medarex, which purchased GenPharm in 1997, has blossomed. The monoclonal-antibody business now has some 300 employees, a brand new research facility in Milpitas, CA, and 60 hectares in New Jersey where it's building a huge development center. It also has a half-billion dollars in cash to make ends meet while it develops its technology and its drugs. "We're on our way," says Lonberg, who is now senior vice president and scientific director of Medarex.

The same can be said for monoclonal antibodies in general, which are in the midst of a remarkable revival. Technologies to make monoclonal antibodies have finally come of age, and the drugs themselves are being touted once again as potential cures or treatments for the entire spectrum of human illness.

Since 1997, the FDA has approved 10 monoclonal-antibody drugs—constituting a quarter of all biotech drugs on the market—with combined sales of well over a billion dollars a year. And perhaps more telling, one in every five biotech medicines in development is a monoclonal antibody. Even biotech giant Genentech, a South San Francisco, CA, company founded with the goal of producing enzyme and hormone drugs, now finds monoclonal antibodies filling half its development pipeline.

Indeed, the story of monoclonal antibodies is more than a fairy tale; it's a lesson in the values of persistence and patience. "When we started with monoclonal antibodies ten years ago, the prevailing wisdom in biotech was, 'Been there, done that, didn't work,'" says Paul Carter, a researcher with Seattle-based Immunex who helped launch Genentech's monoclonal-antibody research in 1990. "Now, everybody and their dog wants to get into antibodies."

FOREIGN INVADERS

As monoclonal antibodies make a comeback, nobody's claiming miracle cures anymore. Having passed through the cycle of "Holy Grail to dirty word," says Lehman Brothers biotech analyst Rachel Leheny, monoclonal antibodies have become a working technology with an established set of strengths and weaknesses.

Monoclonal antibodies are designed by the immune system to bind only to specific target molecules, making them much more precise than typical small-molecule drugs, the relatively simple compounds that have been the staple of the pharmaceutical industry. And unlike other protein therapeutics, which can activate or block only one specific biological process each, monoclonal antibodies can be developed for any target protein or cell type imaginable. This combination of built-in precision and flexibility can mean faster development and lower toxicity. The risk of a potential antibody drug failing in clinical trials because of unwanted side effects is considerably less than it is for small molecules.

"The probability of success is much higher, and the time course of developing them is much quicker," says Geoff Davis, chief scientific officer at Abgenix, a Fremont, CA-based antibody drug company. Considering that pharmaceutical companies now spend an average of 15 years and $800 million to bring a new drug to market, saving a few years in development and reducing the risk of a drug's failing in clinical trials can translate into an enormous profit.

The latest boost to the monoclonal-antibody revival comes from the sequencing of the human genome and the burgeoning genomics industry. Suddenly, pharmaceutical and biotech researchers are deluged with genes, tens of thousands of them, many of which may be valuable drug targets. The result is a gold rush mentality, as researchers race to establish which of these genes and their accompanying proteins are the best targets for inhibiting disease processes. Here monoclonal antibodies—in the guise of laboratory tools that will bind to specific proteins and knock them out of action—represent one of the quickest ways to answer those questions. And once a viable target is nailed down, the low risk and precise targeting of monoclonals can make them the easiest drugs to get to market against it. "They cut right to the chase," says Immunex's Carter.

The object of the pursuit, the antibodies themselves, are Y-shaped proteins that constitute the immune system's first line of defense. They will bind to anything the immune system finds unfamiliar and hence potentially dangerous—say a bacterium or virus—and then hold on tight, calling forth the full range of the immune system's forces to neutralize or destroy the target *(see "Mobilizing Immunity," p. 60)*.

Over the course of a lifetime, the human body generates roughly 100 billion different antibodies. In each case, the base of the Y is virtually identical; the

arms of the Y differ from antibody to antibody, thus providing the vast variability that maximizes the possibility that the immune system will spot almost any conceivable invader.

Researchers have long envisioned inducing antibodies to cure or treat diseases that the immune system either ignores, such as cancer, or causes, like rheumatoid arthritis, lupus and other autoimmune diseases. Biologists have known for decades that if you immunize a mouse with a human cancer cell, or even a single protein from such a cell, the mouse will respond by generating its own antibodies to fight the foreigner off—in effect, an anticancer antibody. If you inject the same cancer cell over and over and over again, your mouse will generate antibodies exquisitely specialized to target the cancer cells you put in.

ADVERSE REACTIONS

It was back in 1975 that César Milstein and Georges Köhler, immunologists at the Medical Research Council Laboratory of Molecular Biology in Cambridge, England, developed a technology to mass-produce such antibodies and, in the process, launched an industry. Köhler and Milstein fused the antibody-producing cells from mice—known as B lymphocytes—with tumor cells that would keep those B cells alive forever in a laboratory.

In the body, immature B cells reside in the bone marrow and contain a full complement of the gene segments that code for antibodies. As the cells mature and migrate into the bloodstream, the segments undergo rearrangement so that each mature B cell makes just one type of antibody—a monoclonal antibody *(see "Genes to Antibodies," p. 62)*. Each of Köhler and Milstein's cell lines would pump out an uninterrupted supply of a single monoclonal antibody, depending on the B cell it arose from. In 1984, their discovery earned the pair a share of the Nobel Prize in medicine, by which time there were roughly a thousand companies trying to cash in on the technology. Most of them would fail.

The problem was inherent in the antibody sources available at the time. Antibodies could be obtained by immunizing mice, as with Raritan, NJ-based Ortho Biotech's Orthoclone, designed to fight organ transplant rejection and the first antibody drug approved by the FDA. (Ortho Biotech has been a Johnson and Johnson subsidiary since 1990.) Or they could be harvested directly from the human victims of a particular disease, as with Centocor's Centoxin.

The catch was that mouse antibodies are, well, not human. The human immune system still considers them foreign and does its best to fight them off—a response known as the "human anti-mouse antibody" response, which not only destroys the antibodies but can lead to kidney failure and death.

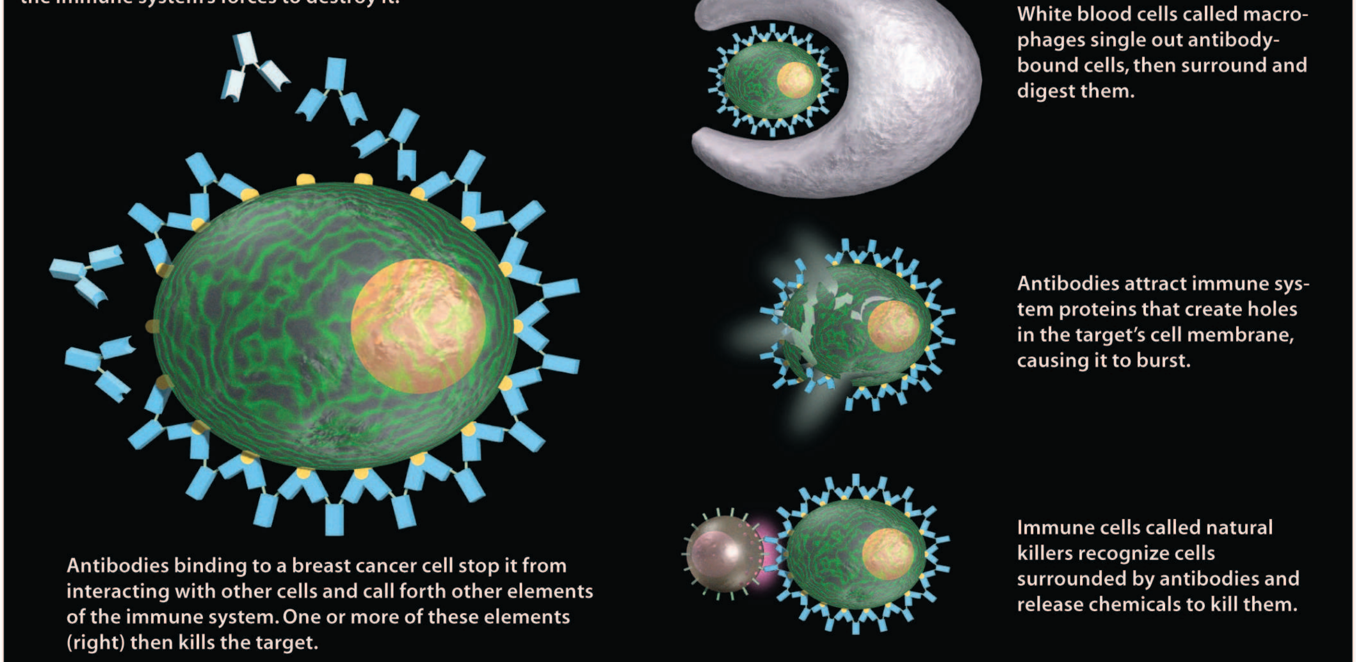
When Orthoclone came on the market in 1986, the pharmaceutical industry suddenly learned just how bad the response could be. While most recipients were fine (and, in fact, Orthoclone is still in use), some patients had severe reactions. "Here was a drug that was specifically designed to suppress the immune system, and you still got a strong response," says Lonberg.

As for antibodies harvested directly from human patients, they simply don't bind to their targets tightly enough to stem disease—or at least that was the case with Centoxin, and the reason its highly publicized clinical trials failed.

Centoxin's failure, says Lonberg, "caused everyone, at least on Wall Street and big pharma, to throw up their hands in despair with antibodies and walk away." Eli Lilly was a classic example. Lilly had purchased Hybritech, the original monoclonal-antibody company, in 1986 for nearly $500 million. After building Hybritech up to 1,400 employees,

Mobilizing Immunity

Antibodies bind to anything the body sees as foreign and activate the immune system's forces to destroy it.



Antibodies binding to a breast cancer cell stop it from interacting with other cells and call forth other elements of the immune system. One or more of these elements (right) then kills the target.

White blood cells called macrophages single out antibody-bound cells, then surround and digest them.

Antibodies attract immune system proteins that create holes in the target's cell membrane, causing it to burst.

Immune cells called natural killers recognize cells surrounded by antibodies and release chemicals to kill them.

JOHN MACNEILL

Lilly sold the company in 1995, post-Centoxin, for only a fraction of what it paid for it.

GETTING HEALTHY

By then, however, salvation was already on the way. It arrived in the guise of antibodies that were considerably less mouse and increasingly human in origin and function. Researchers had begun developing methods to create these blends in the mid-1980s, and the technologies were just beginning to bear fruit around the time Lilly gave up on Hybritech. Chimeric antibodies came first, constructed back in 1984 by joining the gene that generates the constant region of a human antibody, the base of the Y, to the genes that generate the variable regions of mouse antibodies, the outer arms of the Y. The resulting chimera is about a third mouse and two-thirds human. It still binds tightly to the target for which it was designed, while avoiding the bulk of the human antimouse antibody response.

Next out of the research lab were humanized antibodies. Whereas chimerics were one-third mouse, humanized antibodies were less than a tenth. From the mouse came only the very tips of the arms of the antibody Y, just that part of the variable region that binds directly to its target. All the rest was human. But there was a problem: when the tips of a mouse antibody were genetically grafted onto a human framework, the antibody was often unable to grip its target tightly enough.

Cary Queen, a mathematician turned biologist then working at the National Institutes of Health, created an algorithm to analyze the fit between mouse tips and human framework and then figure out just which molecules in the human framework would have to be adjusted, and by how much, to leave the mouse region sitting comfortably atop the arms of the Y and binding tightly to its target. Queen patented the technology and cofounded Fremont, CA-based Protein Design Labs in 1986 to humanize antibodies for its own drug business and for anyone else who might employ its services.

Between chimeric and humanizing technology, antibody drugs started to make it to market, and the industry revival took off. In 1994, the FDA approved the first monoclonal-antibody drug since 1986, Centocor's chimeric-antibody drug to inhibit clotting following cardiovascular surgery. (Johnson and Johnson acquired Centocor in 1999.) The agency then approved three more monoclonal-antibody drugs in 1997—including San Diego-based Idec Pharmaceuticals and Genentech's chimeric Rituxan for non-Hodgkin's lymphoma.

Rituxan and Genentech's humanized Herceptin, approved the following year for breast cancer, may alone have pushed the antibody business back into the boom phase, simply because they were anticancer therapies and so fulfilled, at least modestly, one aspect of the mid-1980s hype. In any case, approval for five more monoclonal antibodies followed in 1998, and four more since. At the moment, nearly 50 humanized antibodies are in clinical trials, targeting the full spectrum of human diseases from psoriasis to heart disease and cancer.

GOATS CURE

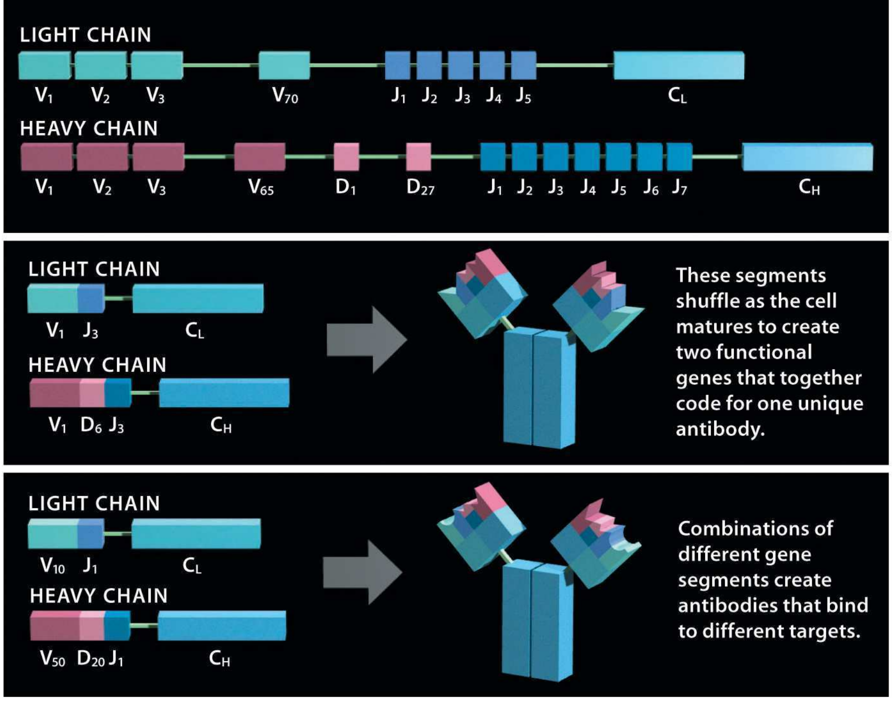
But that's just the beginning, as "fully human" antibodies are now hitting the pharmaceutical pipelines. There are two ways to develop these drugs. In the first, researchers remove the full complement of antibody genes from human B cells and transplant them into bacteria-specific viruses known as "phages." The viruses promptly generate the appropriate antibodies from the newly acquired genes and then "display" the antibodies on their surfaces—one antibody per phage.

"Now we put all those phages into a test tube," explains David Chiswell, cofounder of Cambridge Antibody Technology in Cambridge, England. "Anytime we want antibodies to a particular target, we essentially dip the target into the test tube—which can be thought of as a library of antibodies—and hook out just that subset of 100 billion antibodies that happens to bind specifically to the target."

Method number two is the transgenic mouse with a human immune system—Lonberg's original dream at Medarex, also pursued by competitor Abgenix. Put a target molecule into such a mouse, and you'll get a human antibody out—no human antimouse antibody response to worry about. To make the mice, researchers cloned the gene segments responsible for generating the millions of possible human antibodies, put them all into mouse embryonic stem cells and grew the mice to maturity. It was

Genes to Antibodies

Antibodies are the product of two genes, a "heavy chain" and a "light chain." The larger protein produced by the heavy-chain gene forms the base and inner arms of the Y-shaped antibody, and two copies of the smaller light-chain protein constitute the outer arms. An immature antibody-producing cell doesn't contain functional genes, but rather about 300 gene segments that can create many possible antibodies.



JOHN MACNEILL

A more human mouse: Medarex's Nils Lonberg helped develop mice that produce human antibodies when injected with foreign molecules.

From lab to market: Geoff Davis led the team that engineered Abgenix's version of a mouse that produces human antibodies.

a challenge, says Abgenix's Davis, "because nobody had ever put that much DNA into a transgenic mouse." They also had to inactivate the genes that produced mouse antibodies, which they did in another set of mice, and then bred the two lines together.

While the transgenic mice are the latest antibody technology to come to market, it's still an open question whether they're actually better than any of the other techniques for generating new antibody drugs. "All of these technologies probably produce antibodies that will behave essentially identically when used in people," says Robert Kirkman, Protein Design Labs' vice president for business development. "How do you get the best antibody against the given target is the ultimate question. And that is probably not always going to be the same technology."

Whichever technology ultimately rules the field, it's safe to say that antibodies will play a huge role in genomics and in the biotech industry. If nothing else, says Lonberg, bringing a monoclonal-antibody drug to market can give pharmaceutical companies a way to tackle diseases while they spend the extra years necessary trying to develop a small molecule that will do the same task.

Drug makers are pursuing this separate track because monoclonal antibodies still have two serious drawbacks compared to small-molecule drugs. One is that they are large proteins. This means that they have to be given intravenously rather than in pill form, so they won't be chewed up in the digestive system—although researchers hope to soon solve that problem. (The flip side is that they last considerably longer in the human body, which means they can be administered perhaps once a month rather than once a day.) And the second is that they're expensive to produce.

None of the methods used to generate chimeric, humanized or fully human antibodies can produce antibodies in commercial quantities. At the moment, companies are making antibody drugs by first inserting the gene for a specific antibody into cells culled from hamster ovaries and then growing the cells by the trillions in enormous vats, through a fermentation process not unlike that used to make beer.

The cells in each vat then secrete a single type of antibody that can be harvested from the surrounding fluid every few months. The process is expensive, however, so researchers have been pursuing dramatic biotech solutions to accomplish the same task. In particular, they're creating genetically engineered fruits and vegetables—say corn, alfalfa or bananas—loaded with the desired antibodies, or even transgenic animals to serve as living monoclonal-antibody factories.

Somewhere in central Massachusetts is a "biopharm production facility" built by Genzyme Transgenics. While the company does not like to say exactly where it is, it says that it looks a lot like any other farm—except for the 2,000 or so resident goats that have been genetically engineered with human genes to express monoclonal antibodies or other large-protein drugs in their milk.

According to Jack Green, Genzyme Transgenics' chief financial officer, a few monoclonal-producing goats lactating for a year can match the productivity of an entire fermentation vat of hamster cells. And the goats come with the built-in advantage that if a drug suddenly has a bigger market than anticipated, you don't have to finance a whole new vat at the cost of a few hundred million dollars: you just breed more goats. "The generation time for a new goat is seven months to sexual maturity," says Green, "so in a year you can get to however many goats and whatever scale of production you desire."

After a quarter-century of struggle, monoclonal antibodies have survived to become a mature and exciting technology. And the skeptics are long gone. The question now is how much of 21st-century medicine will be dominated by these remarkable molecules. "Suddenly all this looks real," Lonberg says. "Monoclonal antibodies are no longer somebody's fantasy." TR

Antibodies on the Attack

COMPANY	DRUG/TARGET DISEASE	STAGE
Ortho Biotech (Raritan, NJ)	Orthoclone/Heart, liver and kidney transplant rejection	Approved June 1986
Centocor (Malvern, PA)/ **Eli Lilly** (Indianapolis, IN)	ReoPro/Post-cardiovascular-surgery clotting	Approved December 1994
Genentech (South San Francisco, CA)/ **Idec Pharmaceuticals** (San Diego, CA)	Rituxan/Non-Hodgkin's lymphoma	Approved November 1997
Centocor	Remicade/Crohn's disease, rheumatoid arthritis	Approved August 1998
Genentech	Herceptin/Metastatic breast cancer	Approved September 1998
Millennium Pharmaceuticals (Cambridge, MA)	Campath/Chronic lymphocytic leukemia Campath/Multiple sclerosis	Approved May 2001 Phase II clinical trials
ImClone Systems (New York, NY)	Erbitux/Various cancers	Phase II and III clinical trials
Abgenix (Fremont, CA)	ABX-CBL/Transplant rejection	Phase II/III clinical trials
Tanox (Houston, TX)	AD-439/HIV, AIDS	Phase II clinical trials
GlaxoSmithKline (Middlesex, U.K.)	SB-240563/Asthma, allergy	Phase II clinical trials
Medarex (Princeton, NJ)	MDX-010/Malignant melanoma, prostate cancer	Phase I clinical trials
BioTransplant (Charlestown, MA)	AlloMune/Non-Hodgkin's lymphoma, Hodgkin's disease	Phase I clinical trials

ghana's digital dilemma

BY G. PASCAL ZACHARY

PHOTOGRAPHS BY JASON LAURÉ

Bridging the digital divide in this African nation isn't just a matter of computer-equipment care packages and free Internet accounts.

In on the ground floor: Thomas Fabyan is one of the first Ghanaians to find work in a burgeoning local data-entry industry.

IN THE WEST AFRICAN COUNTRY OF GHANA, ONE OF THE WORLD'S POOREST PLACES, THE BUSY SIGNAL IS A REMINDER OF THE UNFULFILLED PROMISE OF THE INFORMATION AGE.

Making a telephone call here requires persistence. Roughly half don't go through because of system failures, but that's only the start of Ghana's telephone woes. The country has a mere 240,000 phone lines—for a population of 20 million spread across an area the size of Britain. Moreover, telephone bills are inaccurate, overcharges common, and the installation of a new line can cost a business more than $1,000, the rough equivalent of the annual office rent. Lines are frequently stolen, sometimes with the connivance of employees of Ghana Telecom, the national carrier. Phones go dead, and remain unrepaired, for months. Some businesses hire staff for the chief purpose of dialing numbers until calls go through.

The spread of mobile phones has only worsened telephone gridlock. There are more mobile phones in Ghana than wired ones—about 300,000, as of March—but the network is clogged because of a shortage of cell stations. Customers are bedeviled by what operators term "dropped calls." Besides, calls are costly. The price of a one-minute wireless conversation, under the most common plan, is ten times higher than it would be in the United States. "The situation has come to a point of crisis," says Kwesi Nduom, the country's minister for economic planning.

Ghana's telecom mess limits the utility of the Internet, raises the costs of information services—and suggests that the country is mired in the Stone Age, technologically. But the situation here, as in much of sub-Saharan Africa, defies such straightforward conclusions. There is another side to the country's technological profile, a burgeoning homegrown technology culture that explodes assumptions about the inherent backwardness of Africa and the nature of the so-called digital divide.

That there is a gap in the use of information technology between Africans and most people in the United States, Europe and other wealthy regions is unsurprising. After all, development experts have long presumed that lags in technology, much like lags in medicine, stem from poverty—and only reducing poverty can close the technology gap. In the late 1990s, the pioneers of the personal computer, the mobile phone and the Internet saw their technologies as a fresh chance for Africa, an opportunity to leapfrog over what would normally be decades of conventional development. Luminaries such as Microsoft's Bill Gates and Kofi Annan, secretary-general of the United Nations, began campaigning to close the digital divide. Influential international organizations, such as the G8 group of nations and the World Economic Forum, commissioned blueprints for raising the technological level of poor nations, in Africa especially.

So far, these plans have come to little or nothing. In the main, the rich have dropped boatloads of computers onto the poor with no awareness of the environment in which the machines will (or will not) be used. With results lacking, technophiles are starting to recognize what development experts have long known—that no magic wand solves poverty—and to accept that they need to know much more about how people in developing countries live, and what they need and want, in order to close the digital divide.

These are some of the questions that have brought me to Ghana several times in the last two years, first as a foreign correspondent for the *Wall Street Journal*, and later as a visiting professor at the University of California, Berkeley, Graduate School of Journalism. In my visits, I've seen information technologies changing the landscape in unexpected ways. The people I've met are more adept at using these technologies, and are hungrier for them, than most experts believe. But their efforts to put advanced technologies to work in Ghana are often thwarted by the failings of much older infrastructure technologies—the phone system, the electric grid, even the roads.

A visit to a third-floor office in the high-rise known as the Pyramid in Ghana's capital city, Accra, provides a look at one advanced-technology project that seems to be overcoming the barrier of faulty infrastructure. Behind glass walls, hundreds of men and women type at computer keyboards, reading American health insurance claims on their computer screens. Each claims form has been digitized in the United States by Aetna, the large insurer, and sent over a computer network to Accra. Here a typist culls the name, address and other personal information from the form, entering it into a new electronic form, which is then sent back to the U.S.

The key technology in this process is invisible: a satellite link that bypasses Accra's creaky phone system and enables data to be sent overseas instantaneously. To set up the system, the facility's manager, Bossman Dowuona-Hammond, convinced Ghana's government that the satellite would not steal business from the country's national phone company—or be used to interfere with Ghana's politics. "In the past, fear prevented us from getting the tools we needed," says Dowuona-Hammond. "With the right tools, we can compete." Indeed, in one swoop, the satellite link has made a facility in Accra a thoroughly modern business.

All the workers at the data entry facility, from the site manager to the computer networking technician to the typists, are natives of Ghana. American supervisors, located in Salt Lake City and Lexington, KY, visit only occasionally; from their U.S. bases they can view any form in Accra at any moment, peering electronically over the shoulder of any Ghanaian keypuncher, offering help and encouragement.

Local Ghanaian supervisors do much the same. Thomas Fabyan, smartly dressed in black suede shoes, khaki pants and a pressed white shirt buttoned to the neck, prods and cajoles his typists to push their limits. Fabyan sits in the corner of a large open room, with tall windows that overlook the city and give glimpses of the Atlantic Ocean. Along with a colleague, Fabyan is responsible for 275 employees who work over three shifts, round the clock. These typists are paid piece rate: the more records they complete, the greater their pay. The fastest workers can earn nearly three dollars a day, while the slowest take home little more than a dollar, still slightly higher than the pay of a local policeman.

Fabyan, who is 26 years old, represents the new wave of technologically savvy Ghanaians. He used his first PC at the age of 15 and later enrolled in Ghana's top engineering school—then dropped out because he found the courses antiquated. He went to work for a local Internet service provider, where he installed

the equipment required for Web access and later trained others to do the same. The job paid only $30 a month, though, and Fabyan knew he would need more technical expertise to earn a better salary. He decided to sign up for some online programming courses offered by British and U.S. training schools, convincing his father—a financial officer for a local company—to pony up the $800 in fees. Working from a computer in his parents' home, Fabyan devoted more than a year to the courses.

Not long after completing his online studies, Fabyan responded to an advertisement and landed the supervisory job at the data entry facility. There, he can work with an advanced computer network and learn more techniques that he hopes someday to apply in a business of his own. While his chief responsibility is managing keypunchers, in his spare time he recently helped construct an internal Web site where the data entry staff can get answers to common questions. "I want to be serious in IT, and this is a place to start," Fabyan says.

Critics see it differently, insisting that data entry mainly sops up low-skilled workers. "The technological content of this work is quite thin," says Nii Quaynor, a technology advisor to the World Bank and one of only a few residents of Ghana who have doctorates in computer science. "Is there really a future in this for people other than secretaries?" He shakes his head.

Quaynor believes that multinational technology corporations ought to do more for African countries, including creating high-tech product development jobs for local workers. But Ghana is in dire need of jobs—and so the processing of American health-care forms by Ghanaians is potentially ground zero for the birth of a labor-intensive industry in one of the places seemingly left behind by the computer revolution.

After all, processing forms is a worldwide activity that employs millions of people. Most large corporations, from credit card companies to health-care insurers, have contracted out the chore, and contractors run facilities in the Caribbean, Central America and Mexico and throughout Europe, Asia and the United States. Millions of people around the world work in offshore data entry facilities. Yet until Dallas-based Affiliated Computer Services—which processes Aetna's forms along with those of companies such as Liberty Mutual and Health Net—opened this facility in Accra in late 2000, not a soul was employed in this activity in sub-Saharan Africa, says Dowuona-Hammond.

Now, Ghanaians talk of someday hosting 100,000 computer jobs, or more, with keypunching as a base. In March 2002, a second data entry company, Data Management Internationale, opened shop in Accra. The privately held firm, based in Wilmington, DE, is handling government forms for one large U.S. city at its Accra operation. While that project has only 35 workers and is viewed as a pilot effort, the long-term prospects look strong. "We're optimistic about generating the advantages of low-cost labor here," says William Swezey, who launched Data Management's Accra business and is the company's vice president for technical services. "I clearly anticipate other companies coming here, and probably large ones."

The potential for job growth is so great that last fall Ghana's president, John Kufuor, made a surprise visit to the Affiliated Computer Services data entry office. He was impressed by the hundreds of computers he saw (the most in any business in the country) and the spotless working conditions. But what most amazed him, he told his aides, was that work proceeded round the clock, in a country where previously no white-collar work had ever been performed in evenings or the middle of the night.

The growth of data entry in Accra suggests that new information technologies can knit the world closer together by defeating distance and creating jobs. Yet despite working around Ghana's troublesome phone system, Affiliated Computer Services' Accra operation is hampered by other basic infrastructure problems that mock its high-tech sophistication. Frequent power outages—sometimes three or four a day—disrupt work and add to the wear and tear on computers. And the Pyramid building has such poor air conditioning that electric fans are needed to reduce heat in work spaces, in a bid to extend computer life. Such problems mean that, despite the lure of inexpensive labor in Ghana, "the barriers to entry here are very high," says Swezey. "Anyone coming in from the outside will have a hard time getting up and running."

This constant struggle with the local infrastructure is also being waged in Accra's Internet cafés, whose numbers have expanded rapidly thanks to the scrappy ingenuity of their owners and employees.

Two years ago, Accra lacked a single Internet café. Now the city boasts more than 600 of them, a consequence of plummeting prices for PCs and new ways of circumventing the phone system to reach Web servers. An hour online costs anywhere from 75 cents to $1.25, still pricey in a country where many people earn that much in a day. But a few years ago, Web access was far more expensive, when users had to phone places like London or Paris in order to get connected. The rise of Web cafés, combined with free e-mail services such as Hotmail and Yahoo!, means that many Accra residents can receive personal electronic messages for the first time in their lives. This makes "the IT deficit" smaller than people think, says Ravi Amar, a Ghanaian who runs two Web cafés and assembles his own PCs from imported parts. "There's much more computer use here than people realize" *(see "Closing the Gap," below).*

Keeping all those computers up, running and online presents some special challenges, though, as Richard Amaning well knows. A thin and wispy 29-year-old sporting a goatee and eyeglasses, Amaning is the manager of one of Accra's most technically advanced Web cafés, Cyberia. The operation has a dozen PCs powered by 1.4-gigahertz Intel processors and loaded with memory.

Closing the Gap

TECHNOLOGY INDICATORS FOR GHANA	1995	1998
Computers per 100 people	0.12	0.30
Telephone lines	63,067	179,594
Mobile-phone subscribers	6,200	42,343
Public telephone booths	30	1,814
Satellite dish subscribers	0	15,000
Internet host sites	6	253
Radios per 100 people	23.1	68.2
TVs per 100 people	4.04	35.2

SOURCE: GHANA HUMAN DEVELOPMENT REPORT (2000), UNITED NATIONS DEVELOPMENT PROGRAM

Rather than reach its Internet service provider through the city's balky phone lines, Cyberia transfers data through a sophisticated wireless modem, which also increases network speed.

But one afternoon, as Amaning helps a customer print a document, all of Cyberia's whiz-bang technology vanishes—when the electricity goes out. He tells the customers to be patient, and to stay at their computers. Then he runs down a long flight of stairs to the basement, kicks on a backup generator, dashes back upstairs and reboots all the PCs, one after another. That's not the end of it, though. Since the generator is too costly to run any longer than necessary, Amaning must constantly check on neighboring shops to see when their lights return. When power is restored, he tells his customers to halt their work again and shut down, while he goes back to the basement, turns off the generator and switches the café back to public electricity.

months, he learned the basics of PC hardware and networking, then joined a Web advertising agency—one of a handful in Accra—repairing PCs.

Wanting more skills, Amaning took a course on computer networking which helped him to understand the hardware requirements for computer networks, as well as the often idiosyncratic ways that Africans, saddled with poor national telephone and electricity systems, plug into the Web. After the course, he felt ready to manage a Web network. But finding a job took months.

Amaning's break came when a friend, hired by Cyberia to fix a faulty modem, failed at the task and summoned Amaning for help. He got the modem working, and Cyberia's owner hired him. His job is grueling: he works six days a week, from nine in the morning to 11 at night. He earns the equivalent of $125 a month—or roughly four times the average wage in

While Ghanaians should dream of a better future, their reality is sobering. Accra is home to fewer than 50 code writers who can write a program without close supervision. "The pool of experienced people is very thin."

Amaning wants Cyberia to automate the process of switching to and from the generator, but the café can't afford the required equipment. Today, at least, he is fortunate: there are no repeat interruptions. Amaning returns to helping the customer with printing. But the episode is a stark reminder that one must know much more than the ins and outs of computers to manage a network in Accra.

Amaning's computing experiences also illustrate in microcosm the haphazard but promising ways in which Africans, relying largely on their own resources, are coming to terms with the digital revolution and attempting to make it their own. For all the expertise required by his job, Amaning has only completed high school. Eight years ago, an uncle offered him an apprenticeship at his computer repair shop. He liked fixing PCs and, while working, attended a computer training school. For 18

Ghana. To earn even more than that, Amaning will have to improve his skills still further. "My next step," he says, "is to get myself into programming."

Many of Ghana's politicians are beginning to think that would-be programmers like Amaning have the right idea. Sam Somuah, an advisor to President Kufuor, clicks through his PowerPoint presentation on the government's proposed information technology policy before a crowded room in Accra. What is striking about this moment is not the specifics of Somuah's plan, but rather that he has a plan at all. Until late last year, Ghana's political leaders seemed blithely unaware of information technology. Now it is seen as potential national salvation. "There's no way we can raise our standard of living rapidly without IT," Somuah says.

Somuah is chiefly concerned with improving government efficiency through information technology, but he also talks of spawning a generation of technology entrepreneurs. As a first step, the government of Ghana recently reached an agreement with India, which is promising to open a programming training center in Accra. Somuah also wants the government to launch a venture capital fund for technology enterprises. "Who knows, one of you might be the next Bill Gates," he tells the group of young people who surround him after his talk.

Indeed, creating a programming industry would be a coup for Ghana's leaders. Software requires little capital to write and can be sold relatively cheaply all over the world; one hit product could make a huge economic difference in a small country like Ghana, Somuah says. "I believe Accra can become, in time, another India, a Silicon Valley in Africa," adds John Hooper, a Ghanaian graphics designer who opened a three-person company in Accra a year ago.

Setting his sights: Richard Amaning manages a Web café, but his next goal is to become a software programmer.

While Ghanaians should dream of a better future, their reality is sobering. Accra is home to fewer than 50 code writers who can program without close supervision, says Roger Oppong-Koranteng, a Ghanaian information technology manager who trained the president and his cabinet in the use of e-mail. "The pool of experienced people is very thin," Oppong-Koranteng says.

Oppong-Koranteng believes that Ghana will eventually produce information technology innovations but warns against expecting too much too soon. Rather than form a venture capital fund, he says, the Ghanaian government should support programs that "bring Ghana's inexperienced IT people together. Let them talk. When people talk, ideas come up—and someone will pick up the ideas and run with them."

While code writing is an inherently lonely task, in Ghana it is lonelier still, because of the small size of the fraternity and the potential for programmers to get left behind by new technology—a fate that Dan Odamtten is struggling to avoid. At 29, Odamtten has only a high-school diploma. His father wanted him to become a nurse, but he had another idea. "I thought computers were the future," he explains.

To get started, Odamtten took a nine-month course at a computer institute, his mother paying the fees without telling her husband. He learned how to program in BASIC and, as an exercise, wrote a payroll program—but on graduation still found he couldn't get a job. He begged Ananse Systems, a local software house that specializes in supplying programs to small banks, to train him without pay. The company agreed.

Odamtten began by installing shrink-wrapped software for the company's banking clients. After six months, the company decided to put him on the payroll, but only at $30 a month. After another six months, he was asked to write a program in MS-DOS. He has since moved to writing Windows programs too. The company now counts him as one of its best code writers and in January increased his salary to $350 a month, a princely sum by Accra standards.

Rather than celebrate, Odamtten worries about learning new skills. "I can't fall behind," he says, while tapping on his Dell laptop. Sitting on the verandah of the company's office, he is tailoring a database written in Microsoft Access to fit the needs of a rural customer. This is a far cry from writing original programs, but he doesn't have the opportunity for such work. In a small company, he must do many things, from servicing customers to adapting mass-market programs for their specific needs to answering his boss's phone calls. "Software means working long hours," he says.

Odamtten's workload is made heavier by bone-crunching automobile journeys. He typically travels three to five hours on Ghana's poorly maintained and congested roads to visit clients. "Someday we will service customers electronically, over networks," obviating the need for lengthy journeys, he says. But for now, he often rises before dawn to avoid the worst of the traffic.

Odamtten's frustrations are Ghana's writ large: the great potential of information technology—to liberate people from drudgery and saturate their lives with knowledge—is thwarted by tribulations that stem from an earlier, mechanical age.

Information technology isn't the great leveler that enthusiasts champion, but it also isn't as out of reach as skeptics say. The advanced-technology gap between rich and poor nations cannot be explained purely as a function of poverty.

On my first visit to Ghana, I went to the house of a Ghanaian friend. Like many homes in his part of Accra, his had no indoor plumbing, no kitchen, no telephone—not even a street address. My friend had never received paper mail. But two months before my visit he had gotten an e-mail address, an account on Yahoo!, and for a few pennies could send his own message to relatives halfway around the world. In the last two years, I have watched my friend become more adept at using a PC, faster at surfing the Web. But while he remains excited about computing, his discontent grows. He knows much more about the rest of the world than before, but this very knowledge makes him more aware of his own poverty, isolation, and, indeed, the long odds against his succeeding in Ghana.

My friend embodies the riddle, I think, of information technology in Africa and other parts of the developing world. The more I learn about how new technologies are altering ways of working and playing in Africa, the more I become convinced that they both hurt and help. I recently talked with Welsh-born entrepreneur Mark Davies, the founder of Ghana's largest Internet café, BusyInternet. When I asked him what his customers did online, he said, "Four out of five are trying to find ways to get out of Ghana."

The lessons of Ghana are thus complicated. Information technology is not the great leveler that enthusiasts champion, but it also is not as far out of reach as skeptics say. The advanced-technology gap between rich and poor nations cannot be explained purely as a function of poverty. And the most successful efforts at bridging the digital divide may be those that combine the efforts of locals with those of emissaries from the developed world.

On the second floor of BusyInternet, upstairs from the café, a Dutch couple runs a Web design business. An English woman has joined with an East African to launch an e-retailer offering African-made arts and crafts. Data Management, the latest data entry company, has its office on the floor as well—next door to a Ghanaian Web designer. Ultimately, this juxtaposition of foreign energy and local initiative could be just what Ghana needs, says Oppong-Koranteng, who is managing director of BusyInternet when he's not giving computer lessons to his country's president. "The foreigners rub off on us, triggering ideas," Oppong-Koranteng says. "We must make them our own." TR

Software success story: Dan Odamtten's job in software earns him a salary that is princely by Ghana's standards.

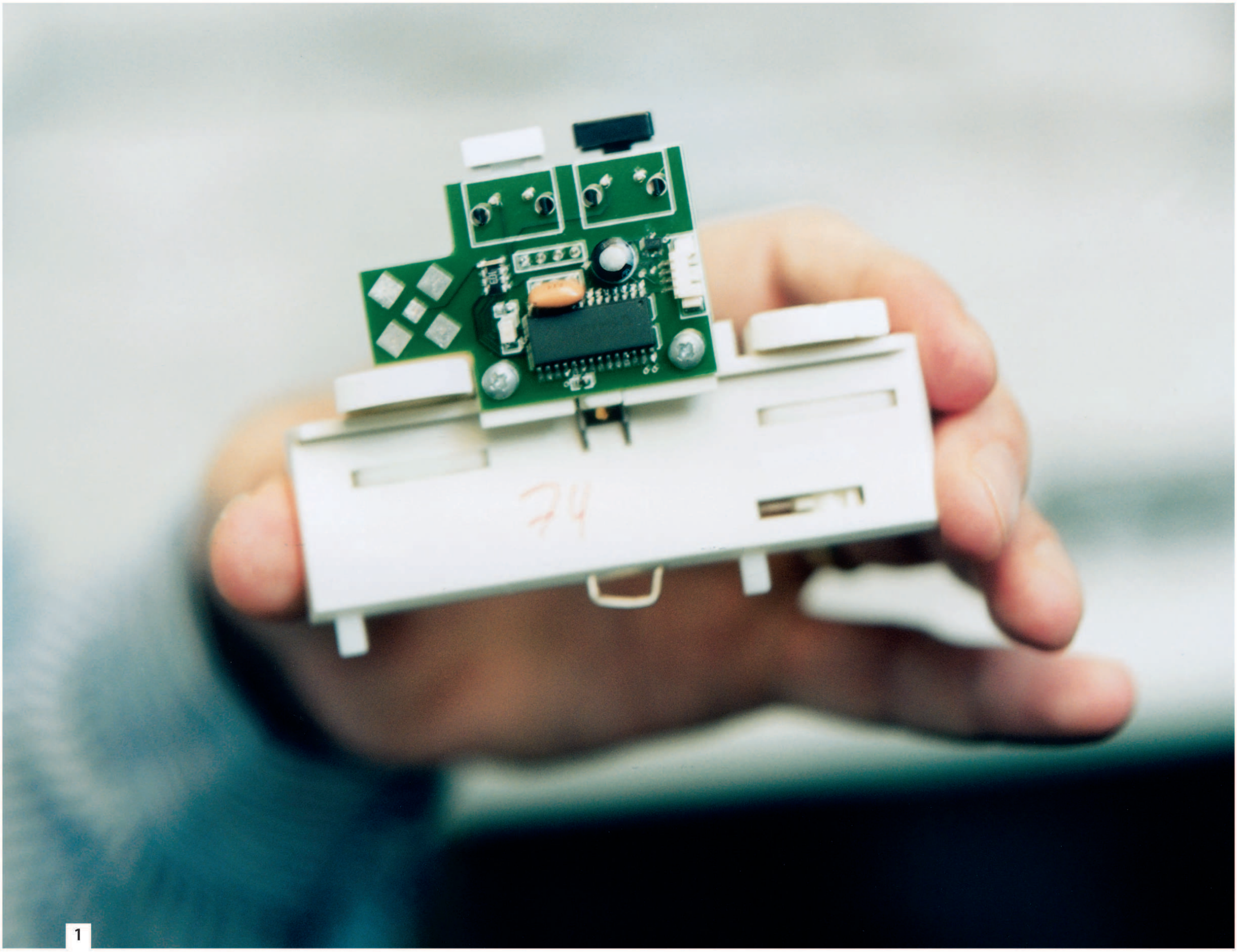
THE PROGRAMMABLE BUILDING

The Internet made our computers infinitely more handy and versatile. Neil Gershenfeld at the MIT Media Lab says our buildings are next.

PHOTOGRAPHS BY KATHLEEN DOOHER

DEMO

Neil Gershenfeld thinks every light switch, power outlet, doorknob and thermostat should be on the Internet. That way, says the director of the MIT Media Lab's new Center for Bits and Atoms, everything from climate control to security could be coordinated through a single Web-based interface. Such a system would simplify both construction and building management by doing away with the separate, incompatible control technologies currently needed to keep a large building comfortable and safe. What's more, he says, embedding computing power in all a building's systems and components could offer unprecedented flexibility and efficiency. Reconfiguring an office space, for example, would no longer mean an expensive and time-consuming rewiring job; switches, light fixtures and other components could be moved around on power tracks and reprogrammed at will. But there's a catch. "The Internet, as we use it now, doesn't work for every light switch and outlet," Gershenfeld says. Standard networking technology is too expensive and complicated for such massive deployment. So Gershenfeld's team is developing cheap, simple Internet devices able to network themselves with a minimum of human intervention. *Technology Review* senior editor Rebecca Zacks got a look at the technology in Gershenfeld's lab, where he demonstrated a whole new way to turn on the lights.



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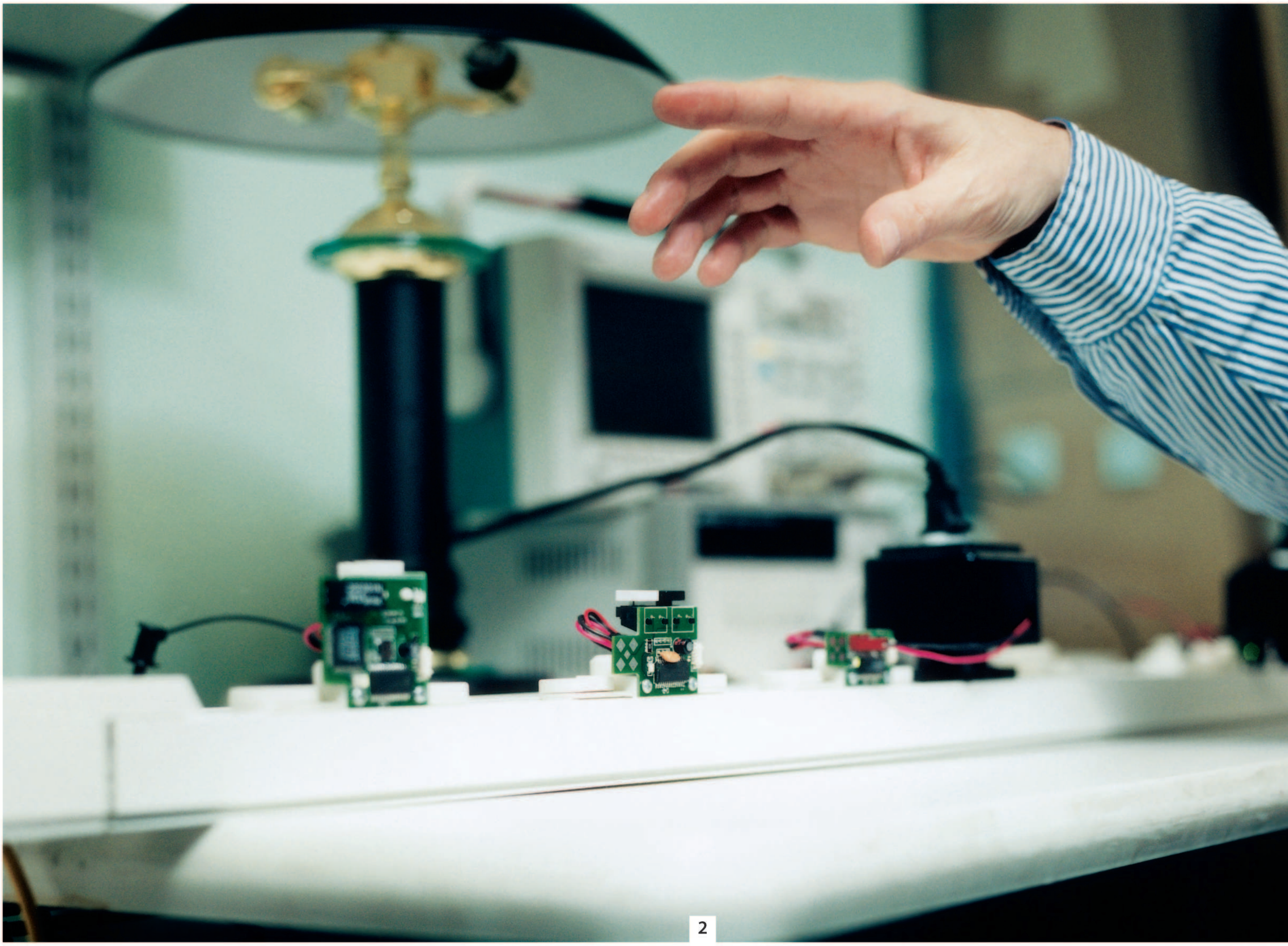
1. SIMPLE SITE. At the heart of Gershenfeld's system is a fleet of small, cheap computing devices. "This is an Internet site," says Gershenfeld, picking up one of the devices and pointing to its small green-and-black circuit board. This particular device, he adds, is also a switch; it boasts two buttons, one white and one black, mounted with the circuit board on a large white base. "All of this stuff plugs into a track," Gershenfeld says, grasping the base. "It's like a track for track lighting, but it's unusual because it has two extra wires on it, and those extra wires carry data." The tracks are already commercially available, he says, and could be installed throughout a building. The switch itself is built with off-the-shelf components, including a very simple microprocessor. All told, "this might be a couple dollars' worth of parts," he says.

2. PLUGGED IN. Gershenfeld snaps the switch into a track set up on a desktop, positioning it between two similar devices of different size. Gershenfeld gestures to the device on the right-hand end of the track: "This is also an Internet site, but this one isn't a switch—it's an AC outlet." In fact, a desktop lamp is plugged into the outlet, though the lamp is currently off. A small green light glows on the switch Gershenfeld has just added to the track, indicating that the device is drawing power from the track. But when he pushes the buttons on top of the switch, trying first the white one and then the black one, "nothing happens because this switch has no life experience—it doesn't know what to do yet."

3-4. PROGRAMMING TOOL. Gershenfeld sets out to remedy the situation. "I'm going to take a sophisticated programming implement, a pair of tweezers, and I'm going to introduce the switch to the outlet," he says. "It doesn't have to be tweezers. That's just what we happen to have around the lab." He touches the tips of the tweezers to tiny metal pads on the front of the switch, then to identical pads on the outlet device. "What happens when I do that," he explains, "is the switch sends a message to the network that says, 'Hello, world, Neil just did something to me.' The outlet sends a message back, saying, 'Oh, Neil did something to me too.'" As Gershenfeld wields the tweezers, a nearby oscilloscope monitors data traffic on the track. "And then they say, 'Well, if he did it to me and then he did it to me, he must mean that we're related to each other.' So then they exchange over the network the equivalent of their business cards. One says, 'I'm an AC outlet, here's my address on the network,' and the other one says, 'Oh, I'm a switch, here's my address on the network.'" This digital conversation is represented visually by a forest of red spikes flashing on the oscilloscope's screen.



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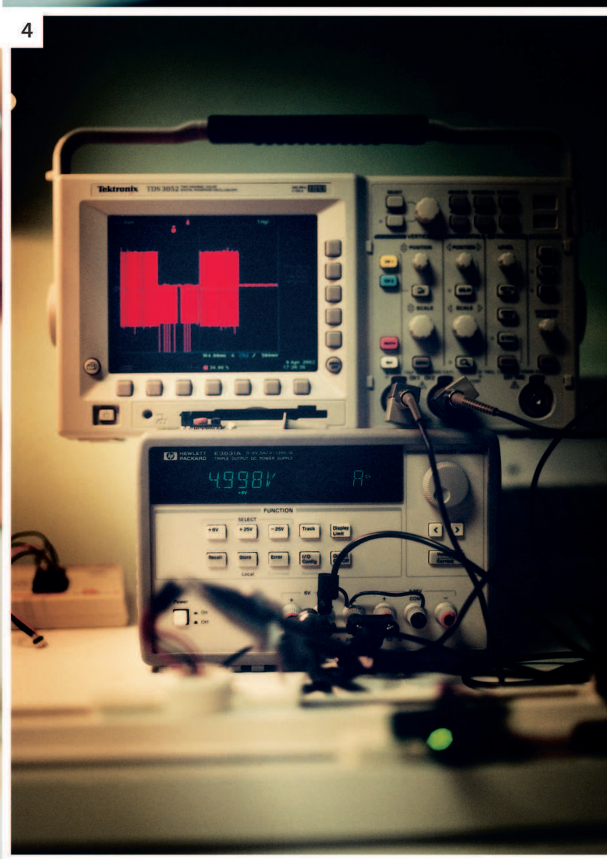

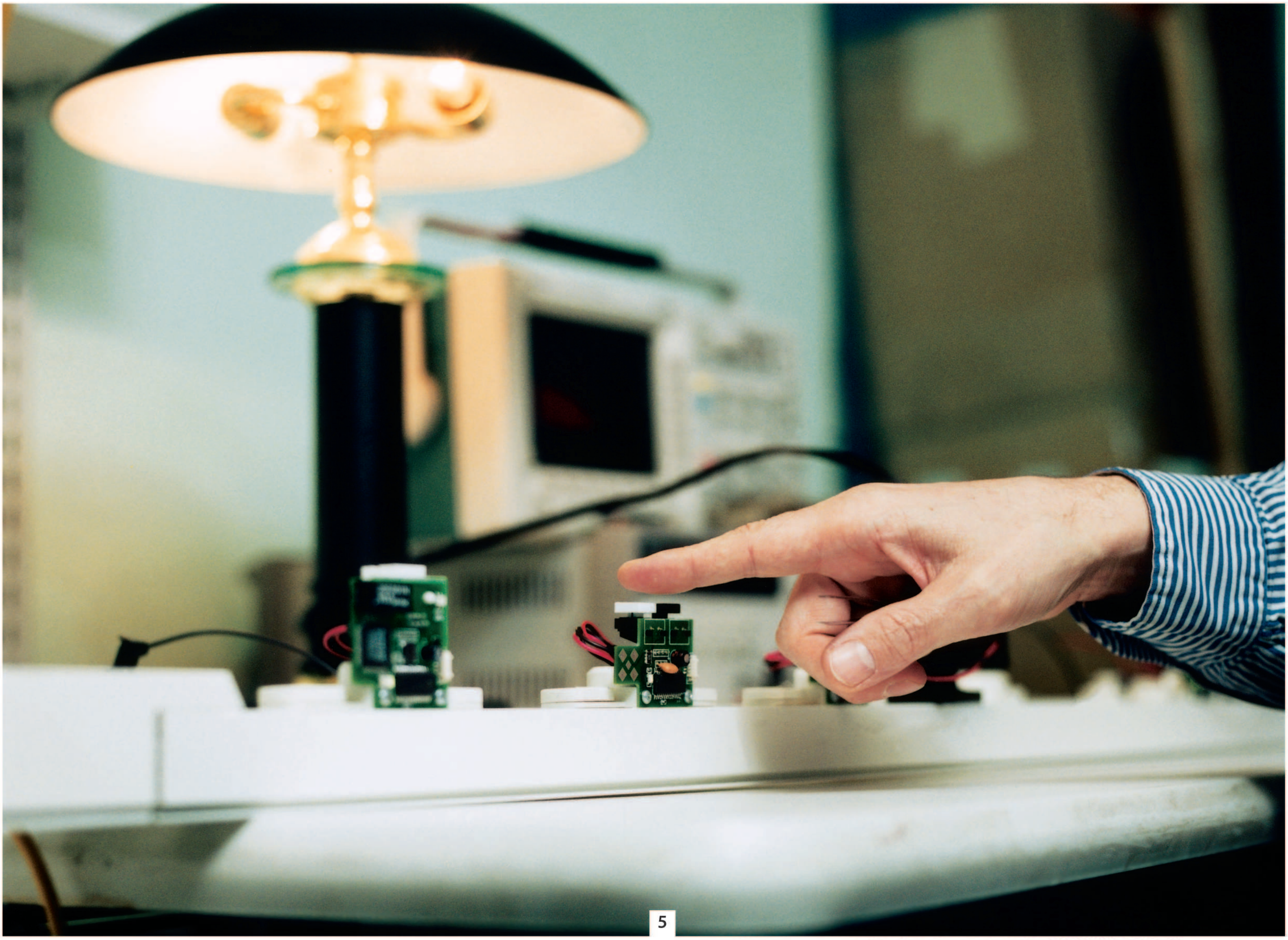

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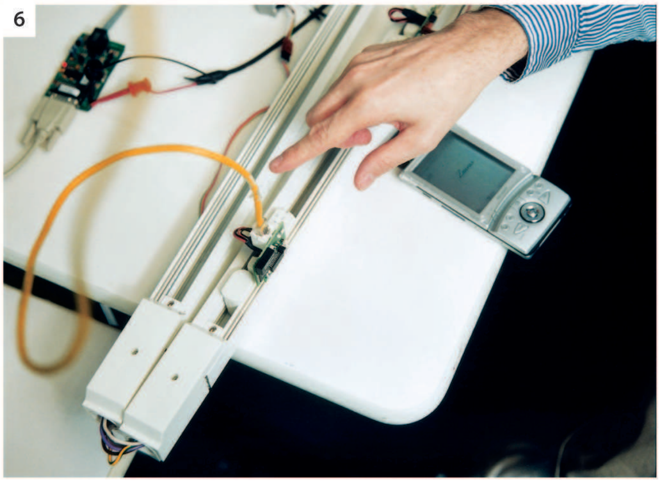
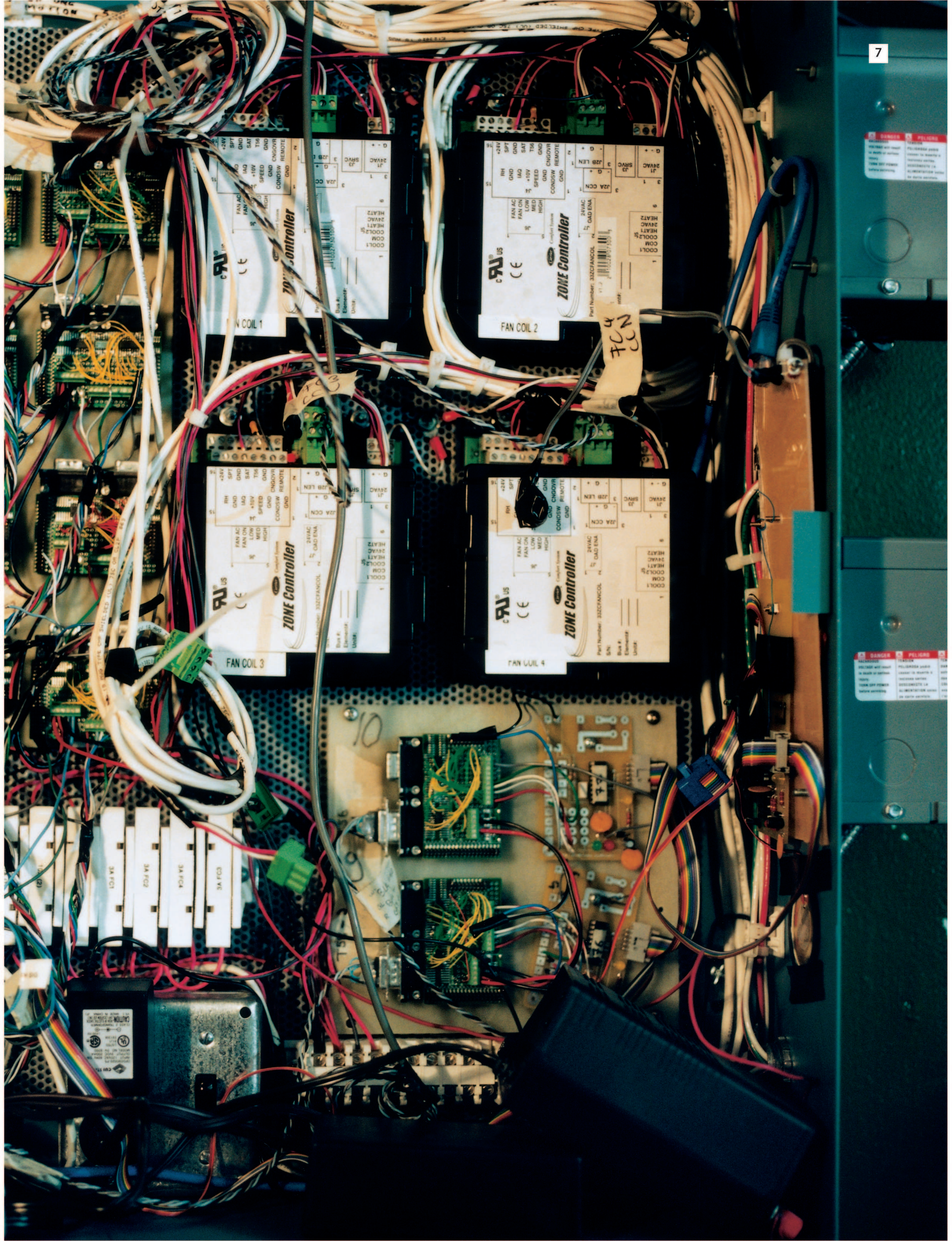


5. LIGHTS ON. Now that the switch and the outlet have exchanged their data, Gershenfeld says, "if I push the switch, the light turns on and off." He pushes the white and black buttons and the lamp responds accordingly. "And I can take the switch out and plug it in somewhere else, and it still does the same thing, because the behavior's associated with the switch, not the location of the switch." What's more, he says, each switch can easily be reprogrammed to control a different outlet (or thermostat, electric door lock, and so forth). Such flexibility could be a boon for building construction, he says, where traditionally "a lot of work goes into making drawings of wiring of what gets connected where. Then a lot of work goes into following those diagrams, and then, if you get all of that right, a lot of work goes into eventually changing it when the dot com goes bust and you need to rearrange the building."

6. EVERYTHING ONLINE. The system also opens the possibility of controlling all of a building's systems via the Internet. "This is the Internet," Gershenfeld says, plugging a yellow cord into the left-most device on the track. That device, he explains, converts the signal coming through into a lower-bandwidth format that runs on the track. He picks up a personal digital assistant and wirelessly connects to a very simple Web page that says "Off." With a tap of the stylus, the page switches to "On," and the lamp turns on. "What's happening is the PDA is sending a message out through a radio to the Internet. The message comes down the track directly to the socket, and it tells the socket to turn on and off"—bypassing the physical switch entirely.

7. GET REAL. The Media Lab's new building, planned to open in 2004, will give the system its first large-scale test—going way beyond light switches and, with the aid of corporate sponsors, moving toward a commercial version of the technology. Gershenfeld opens a circuit box, revealing a jumble of wires and devices that represents early efforts to marry conventional heating, cooling and ventilation technology with Internet-based sensors, thermostats and switches. "The expectation is that in the run up to the building's opening all sorts of stuff will break," pointing the way toward refinements, he says. "The building is a chance to show that the stuff can work on a grand scale, not just as a little toy demo."

7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3A FC2
3A FC4
3A FC3
CAUTION
DANGER
PELIGRO

WHEN PATENTING WORKS

In April, after four years of bitter and expensive patent litigation, the computer chip maker Intel agreed to pay Huntsville, AL-based Intergraph a whopping $300 million. It is one of the largest patent settlements in history. Don't feel bad if you missed the news, though. The press pretty much missed it, too, at least in part because word of the agreement was largely overshadowed by news of Intel's relatively upbeat (big news in these hard times) quarterly earnings report.

The press missed an important opportunity, however, because the case says a lot about the strength of our patent system. To be sure, I am frequently critical of deficiencies in this system, noting, for instance, that the U.S. Patent and Trademark Office often grants unnecessarily broad or obvious patents. But even when I make these critiques, I am very mindful of the fact that, however flawed, our existing system often does do its job by protecting patent holders against those powerful players who might try to get around or steal away or somehow wrongfully employ their intellectual property. And that's really what this case is about.

The case centered on Intergraph's claim that, to develop its Pentium processor chips (the first of these workhorses appeared in 1993), Intel illegally appropriated technology covered by five Intergraph patents. The lawsuit saw many twists and turns, including Intel's argument that Intergraph's patents were invalid and that, in any case, they were covered by a cross-licensing agreement Intel had made with a third party.

Notably, though, Intel never really challenged the claim that it had used Intergraph's technology. Nor is there much question that it tried to use its tremendous size to pressure Intergraph into a licensing agreement.

Intel spokesperson Chuck Mulloy emphasizes that the settlement ought not be construed—legally speaking—as an admission of guilt by his firm. But let's face it: even giants like Intel don't part with nearly a third of a billion dollars unless they have to. And as Intergraph general counsel David Lucas bluntly put it before the settlement was reached, by first trying to muscle Intergraph into an unfavorable licensing arrangement, and then by shutting Intergraph off from technical information about its Pentium line, Intel had acted like "the schoolyard bully."

Those far more knowledgeable than I am about the history of semiconductors might dispute the validity of the five Intergraph patents in question. As I understand it, Intergraph, now a software firm but then in the chip design and workstation business, was incorporating ideas like multiple pipelines and large caches into its microcomputer chipsets well before Intel's designs. But there are undoubtedly other firms besides Intergraph (as Intel also argued in court) that might have claims to some of these ideas.

Nonetheless, as a patent holder, Intergraph is recognized by the U.S. government as the rightful owner of powerful chip design technology. And as such, the firm is entitled to the protection its patents afford, meaning that the big guys on the block—in this case Intel—must play by the same rules as everybody else. To my mind, it's nice when the patent system can be used to enforce this rudimentary sense of equal intellectual-property justice under the law.

Along these lines, I am reminded of the late Jerome Lemelson, who was far and away the most prolific independent inventor of the 20th century—with more than 500 patents (second only to Thomas Edison in U.S. history) covering everything from machine vision to bar code scanning. A few years before his death in 1997, Lemelson told me how he came by his ardent support for the patent system.

As he recounted, back in the 1950s, when he was in his 20s and his work focused mostly on toy designs, he had gone to a major cereal manufacturer with his idea for a cutout face mask that could be printed on the back of a cereal box. The company said thanks but no thanks. But sure enough, a few years later, a shocked Lemelson noticed that the same firm began printing its cereal boxes with cutout face masks on the back.

The big guys on the block—in this case Intel—must play by the same rules as everybody else. It's nice when the patent system can be used to enforce equal intellectual-property justice.

Lemelson never got over the audacious ripoff of his work. And he never forgot that patents were his only practical means to protect himself against powerful players in the marketplace. Lemelson's tale is worth repeating because it is so simple and clear. At its core, our patent system is designed to prevent such wholesale theft.

So here's to Intergraph. Yes, it may be a *Fortune* 1,000 firm. But it is still a mighty underdog in its patent battle against Intel. And while it won a substantial settlement in this case, it continues to champion its patent rights in a separate dispute in which it claims that Intel's new, 64-bit Itanium processor design illegally includes patented Intergraph technology. This related case, only now coming to trial, may not earn Intergraph a whole lot of press either. But Intergraph and the rest of us should take some comfort in the fact that the biggest players with the most money don't always win. TR

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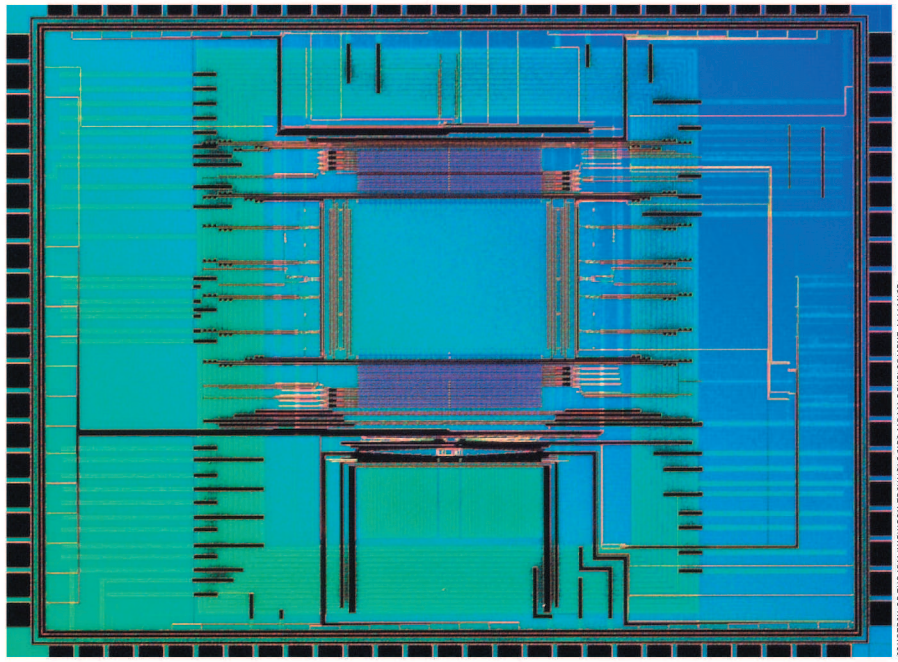
VISUALIZE

HOW TECHNOLOGY WORKS



COURTESY OF THE IBM/INFINEON TECHNOLOGIES MRAM DEVELOPMENT ALLIANCE

By Tracy Staedter | Illustration by John MacNeill

MAGNETIC RANDOM-ACCESS MEMORY

Simple magnets offer a computer storage solution

Your computer has a leak. The dynamic random-access memory (DRAM) technology inside it relies on electrons stored in microscopic cells. The electrons escape frequently, though, and the cells must be electrically recharged thousands of times per second to keep your electronic files intact. But a new kind of memory may end that. Magnetic random-access memory (MRAM) stores data in the spin of electrons inside tiny magnetic sandwiches *(see "Computing's New Spin,"* TR *January/February 2001)*. The sandwiches don't lose their magnetism—or memory—even if the power goes out. What's more, MRAM has the potential to store as much data as DRAM, write it faster and access it almost instantly—all while consuming less energy.

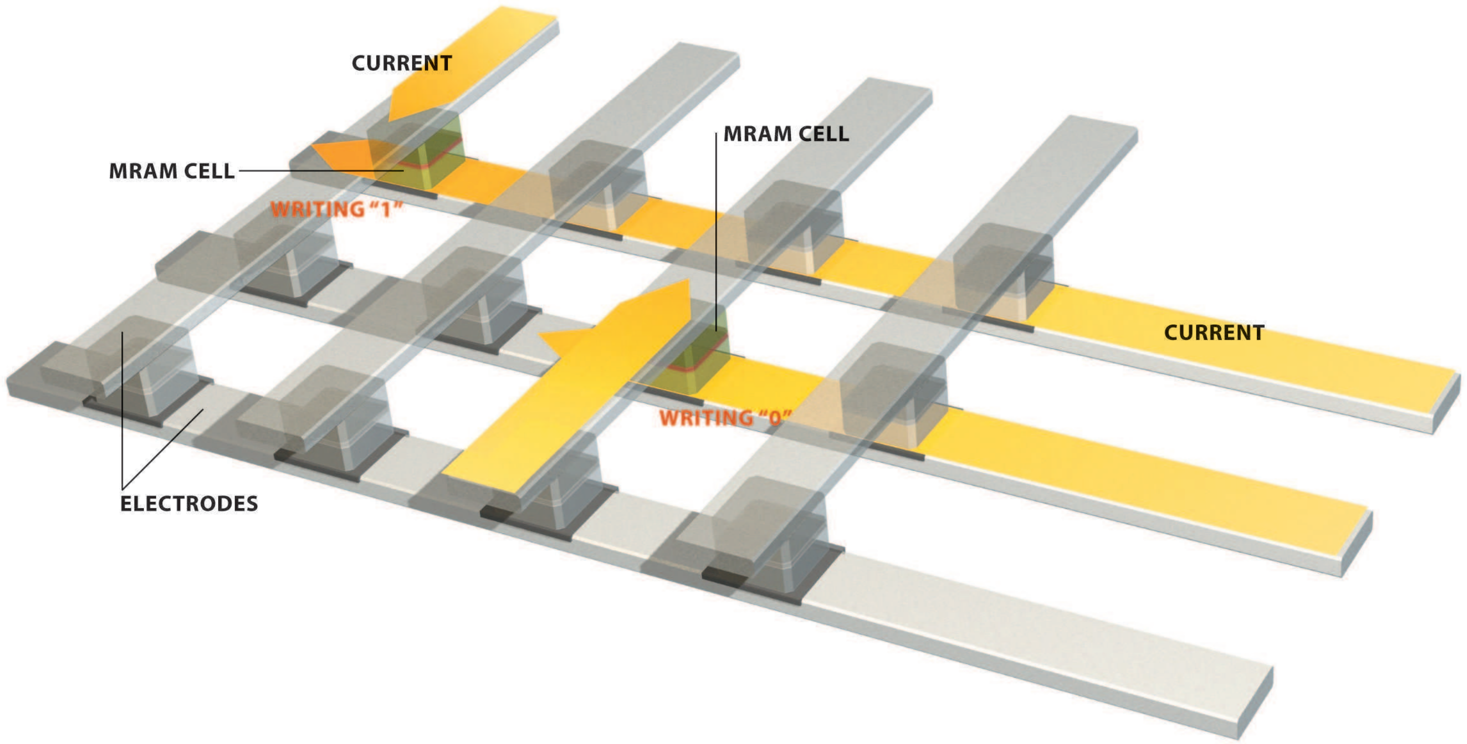
A magnetic random-access memory cell is made of a thin insulating layer sandwiched between two magnets. Depending on the way their electrons are spinning, the magnets can have fields that point in the same direction or in opposite directions. These two states correspond to the ones and zeroes of digital memory. Each cell sits at the intersection of perpendicular electrodes that run above and below it.

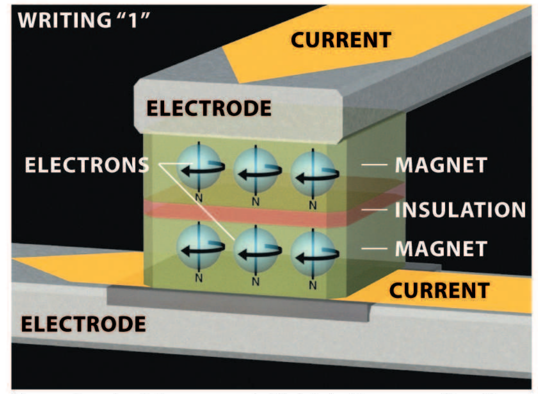
To write a bit, electric current must pass through two intersecting electrodes. At the cross point, the currents induce a magnetic field sufficient to alter the spins of electrons and therefore the cell's magnetic orientation. To read the data, a lower-voltage current travels along the bottom electrode, through the specific memory cell, and out along the top electrode. If the two layers are magnetized in the same direction, their electrical resistance is low, indicating a one; if they are magnetized in opposite ways, resistance is high, indicating a zero. An electrical sensor at the end of the top electrode reads the resistance and determines the binary state of the cell that was read.

Motorola, IBM and Eden Prairie, MN-based NVE are developing the technology with funding that comes in part from the U.S. Defense Advanced Research Projects Agency. If they succeed, we could see MRAM devices as early as 2004. TR

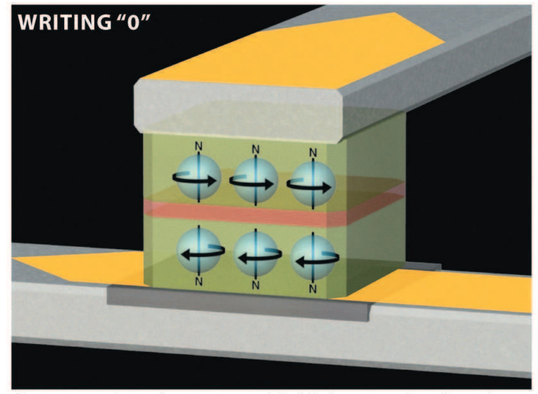
For an animated version of this illustration, go to www.technologyreview.com/visualize

WRITING



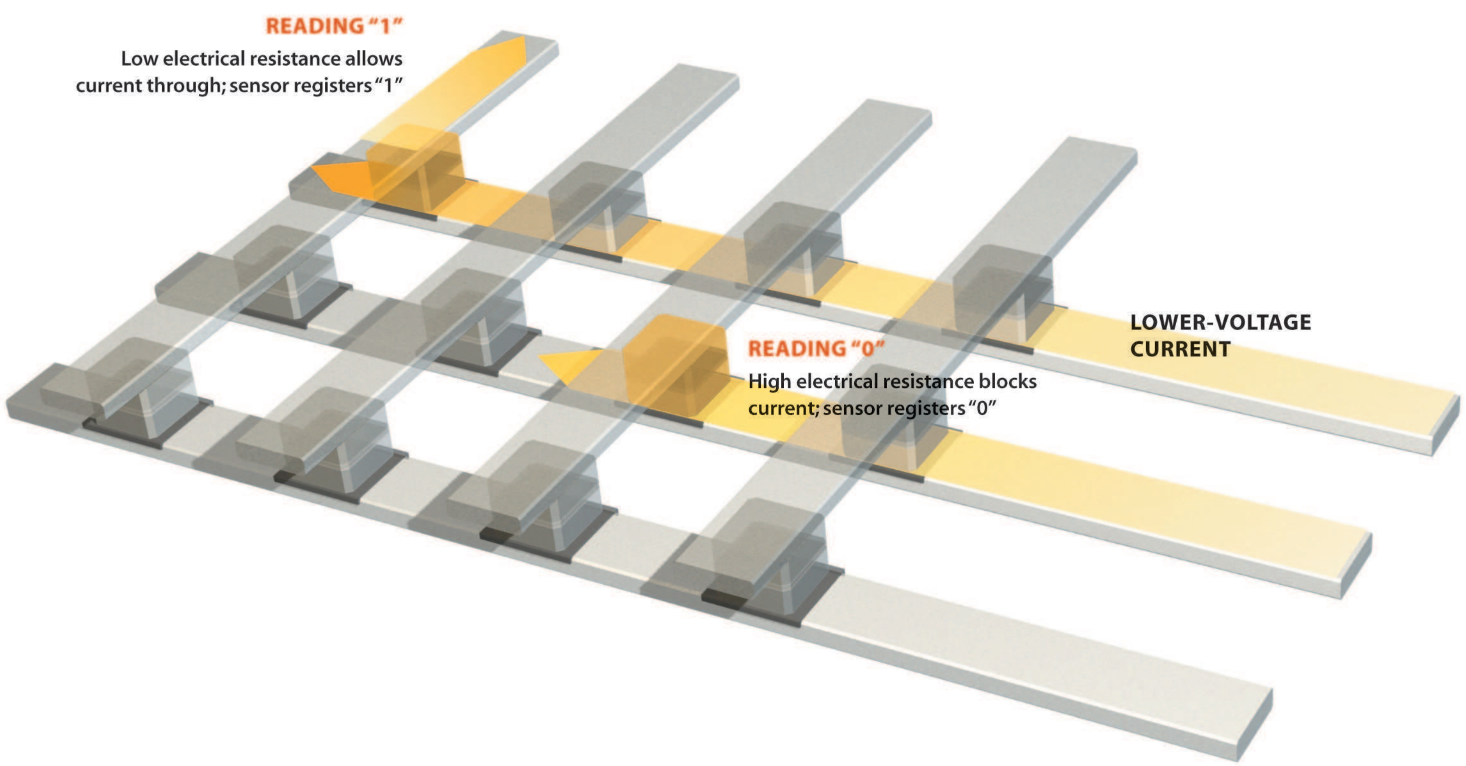


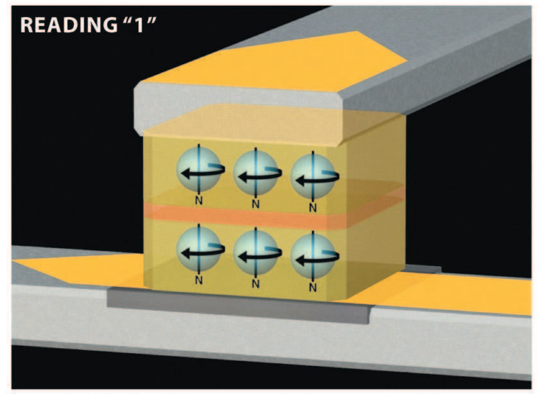
Currents orient the magnets' fields in the same direction.



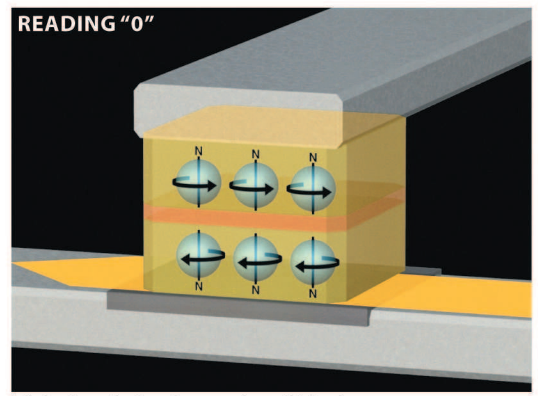
Currents orient the magnets' fields in opposite directions.

READING





Low electrical resistance in cell allows current through.



High electrical resistance in cell blocks current.

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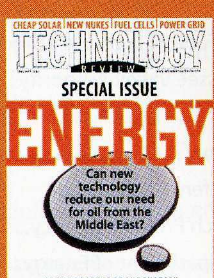

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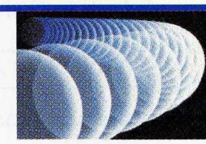

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DRIVE, SHE SAID

A silent-movie ingenue—"the first movie star"—was an automotive innovator

Turn signals and brake lights are standard on all automobiles manufactured today—in fact, it's hard to imagine cars without them. But close to a century ago, when the automotive industry was just revving up, such amenities were brand new. The inventor of the earliest versions of both was Florence Lawrence *(above)*, who was, at the time, the highest-paid film actress ever.

Lawrence was born in 1886 in Hamilton, Ontario, as Florence Bridgwood. Her surname was changed when she was four to match her vaudeville actress mother's stage name. Acting was, apparently, in Lawrence's blood: she started in silent films in 1907 and by 1910 was so popular that she became the first actress to have her name used to advertise a picture; indeed, she was arguably the first movie star. At the height of a career playing heroines on the silver screen, she invented two key automobile safety devices.

According to Kelly R. Brown's 1999 biography *Florence Lawrence, the Biograph Girl*, Lawrence was an automobile aficionado at a time when relatively few people—by today's standards—owned cars. "A car to me is something that is almost human," she later said in an interview, "something that responds to kindness and understanding and care, just as people do." She soon set about improving the vehicles she loved. By 1914, she'd invented the first turn signal, called an "auto signaling arm," which attached to a car's back fender. When a driver pressed the correct button, an arm electrically raised or lowered, with a sign attached indicating the direction of the intended turn. Her brake signal worked on the same principle: another arm with a sign reading "stop" raised up whenever the driver pressed the brake pedal—the essential concept behind today's brake lights.

Lawrence's mother, Lotta Lawrence, got into the act, too: she patented the first electrical windshield wipers, which used a system of rollers, in 1917. But her daughter's inventions *weren't* properly patented, and others soon came out with their own, more refined versions. By the time the first electrical turn signals became standard equipment on Buicks in 1939, Lawrence's contributions were long forgotten. The previous year, in chronic pain from a rare bone marrow disease and with her film career foundering, Lawrence had committed suicide. Her grave in Hollywood, CA, unmarked for decades, received a marker in 1991 that read "The First Movie Star." Her automotive innovations went unmentioned. TR

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